The Influence of Shared-Representation on Shared Mental Models in Virtual Teams

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Abstract. This paper reports a laboratory experiment investigating the influence and effects of shared-representation facilities on collaboration and shared mental models development in virtual teams. The experiment has two experimental conditions; with or without shared-representation facilities. Participants were asked to work in pairs on a 'house hunting' scenario. The results showed no significant difference in the overall performance between the two conditions, however shared mental models development was significantly higher where partners were able to use shared-representation facilities.

Keywords: shared mental models, shared-representation, collaboration, virtual teams.

1 Introduction

Virtual teams have become commonplace in the world today where organizations are constantly searching for better ways to plan and carry out their business. These teams consist of geographically distributed members who rely heavily on communication technologies for effective collaboration. The use of collaborative tools has seen a rapid incline due to the decreasing costs and availability of the internet. Technologies such as email, instant messaging, internet phone, video conferencing and application/desktop sharing seek to offer better solutions to aid collaboration. These technologies contribute and affect collaboration differently depending on the types of task being performed and the nature of the team.

Many organizations have adopted the use of shared publication spaces to rectify the problem of sharing restriction in distributed workplaces. This is often where a collaborative portal brings all project information into one central location that can be accessed anytime, anywhere very easily [1].

This paper describes a study that evaluates the effects of some aspects of collaborative technologies such as desktop sharing or shared-representation, on decision making and shared mental models. Shared-representations allow two or more people to view or share the same visualization and resources at the same time, during synchronous collaboration, for example in a virtual meeting.

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The objective of this study was to test how the availability of shared-representation affects the overall level of collaboration in virtual teams as well as the development of the teams' shared mental models. A laboratory study was carried out where participants were divided into two groups, for two experimental conditions. In the control group, participants worked in pairs on a problem-solving task without the use of shared-representation facility. However in the second experimental group, participants also worked in pairs, but were able to use the shared-representation facility during the task. The results such as performance, satisfaction, shared-mental models development and collaboration were then compared between the two conditions.

1.1 Virtual Teams

Virtual teams are fundamentally groups of individuals separated by distance and/or time, yet have common tasks to perform [3]. Edward and Wilson [4] have divided virtual teams into three categories - project teams, service teams and process teams. Project teams only come together for a finite period of time in response to a project brief; some exist as a resource on call for the resolution of problems or for advice, these are called service teams. The last group, process teams exist over an undefined period to respond to ongoing needs within a certain domain. These teams however are more complex than traditional co-located teams, and with the nature of virtual teams, members must work apart more than together, which reduces the amount of formal and informal communication. This in turn may result in members feeling isolated and lacking the sense of belonging. All these factors may impact on the development of their shared mental models development, which many organizations have to overcome.

1.2 Shared Mental Models (SMMs)

The increasing use of technologies has contributed to the complexity of many tasks performed in the workplace, making it difficult for personnel to complete their work independently. Many organizations therefore rely on work-teams consisting of members from different fields or of the same background to carry out set tasks and projects. This emphasizes the importance of SMMs in virtual teams.

Mental models (MMs) are organized knowledge structures that allow individuals to interact with their environment, to predict and explain the behavior of the world around them. They also allow individuals to work together in a team whilst recognizing relationships among components as well as other members within the environment [2&4].

Cannon-Bowers et al [3] suggested that teams needing to adapt quickly to changing task demands might be drawing on shared or common MMS using the rationale that members must predict what their teammates are currently doing and what they are going to need in order to accomplish that task. Orasanu and Salas [6] state that in order for a team to work together successfully, members must perceive, encode, and retrieve information in similar ways, thereby constructing similar individual MMs. This will allow teams to tightly coordinate with each other even under high pressure

conditions as members are able to anticipate and predict each other's needs and reactions. Bristol [2] summarized the following:

- Knowledge convergence leads to similar individual MMs
- Similar individual MMs leads to similar problem solutions
- Similar problem solutions help anticipation of another's needs or actions
- Anticipation enables team coordination without extensive communication

This concept has mainly been developed for co-located teams where members work closely together all the time, and develop situation awareness of each other within the teams. However, when considering distributed teams, where members seldom communicate with each other directly, it is unclear how these virtual teams of skilled members develop their shared mental models or how their locations and distances affect this development.

1.3 House-Hunting Experiment

The experiment for this study is referred to as 'house-hunting'. This scenario has been chosen as it is easy to understand and allows volunteers to take part without having prior knowledge of the task. Spatial information is known to be difficult to verbalize and therefore very suitable for this experiment testing distributed collaboration where participants cannot communicate face-to-face. One of the objectives was to compare performance between conditions. In the first condition, both participants working in the same team could see the same spatial information whereas the other condition, participants purely relied on each other to verbalize all the information. Participants were asked to bring someone they know to the experiment, who they could then work together with in a pair.

A pilot study was conducted to gather a list of important information people need when looking for a house to let. This included information on price, crime rates, transportation, distance to shops and parking availability for example. The locations of where all the ten properties to let were only given to one of the participants within a pair. This means for one of the conditions, the partners had to describe where houses were to each other.

It was decided that the information such as rent would be expressed in areas as shown in Figure 1. This information was given to the other partner who did not have the locations of the properties. This meant partners had to clearly communicate with each other and this also ensured that collaboration was necessary in order to complete the task.

Participants working together in a pair would need to combine information from Figure 1 together in order to establish how each of the houses fall into different price brackets for rent. Participants were also given a different set of criteria to their partners. This was to ensure that the experiment simulates the conflicting goals and needs in a real working environment as well as the need to compromise. It also was important to avoid one participant taking charge and become the main decision maker for the pair if they had the same criteria to work towards.

Fig. 1. Rent expressed in area available to participant 1 (left) and the locations of properties available to participant 2 (right)

This experiment also allowed the investigation of SMMs in the sense that participants had to work together to problem solve as well as to make decisions based on collaboration and the development of SMMs. This experiment has three main hypotheses to be tested as follow:

H_1: There is a difference between the levels of shared mental models development in the two experiment conditions

H_2: There is a difference in the overall performance between the two conditions

H_3: There is a difference on the user experience such as the level of satisfaction and perceived difficulty when comparing two conditions

2 Method

Participants. 32 paid volunteers took part in the experiment forming 16 pairs; eight for each experimental condition (17 male; 15 female; mode age group of 22-25). Participants were asked to bring a friend along with them to the experiment, so they could work as partners.

Design. The experiment was a between-subject design. All participants and their partners make the total of 16 pairs, hence eight pairs per each condition. The 2 experimental conditions are:

1. 'Shared-representation' or 'SR'
2. 'No shared-representation' 'NSR'

Participants were located in the same room but were separated from their partners by a partition screen between their desks. This prevents them from being able to directly share information with each other or to communicate face-to-face during the experiment. However they were able to communicate vocally.

Task. Participants were asked to select three houses they would like to rent together, from a selection of ten. In a pair, participants working together would get separate pieces of information to their partners. However, they needed to collaborate and work together in order to combine and utilize all the available information as a team. The

information was divided to encourage collaboration. It was also divided to ensure that partners could not have completed the task properly unless they collaborated. Partners were also given conflicting criteria for the required house. This is to simulate many of the real life situations where different needs and requirements with individuals collaborating conflict and therefore compromises have to be made. Participants were given 40 minutes to complete the task.

Materials. All sessions were video recorded by two video cameras on tripods, i.e. one camera per partner working on the task. Booklets containing the information on the task as well as the instructions were given to all participants at the start of the experiment. Participants within pairs were given a list of criteria for the potential house-to-let, which was not however, given to their other partners, who received another set of conflicting criteria.

A partition screen was used to separate participants. Each participant was given a laptop to use during the experiment, which they used to browse through the PowerPoint slides containing information about different properties. These laptops were also attached to a spare monitor on the other side of the partition screen, on their partner's desk. This allowed the driving laptops to produce a copy or a projection onto the spare monitor. In the SR condition, the spare monitors were switched on, meaning both partners would have their laptops as well as a spare monitor each, where they could see a copy of their partner's screen. This spare monitor was switched off for the NSR condition where participants were not allowed to see their partner's screen. After the task completion, post-experiment questionnaires were given to all the participants. This was to gather subjective data such as the perceived difficulty of the task, the level of satisfaction w the final selection of houses as well as collaboration.

Procedure. Once the participants arrived in their pair, they were asked to be seated on either side of the partition screen. They were asked to read and sign the consent forms before they were given a briefing on the task as well as their information booklet. Participants were allowed a few minutes to familiarize themselves with all the given information and their own criteria. They were also informed that they did not have the same slides as their partners. The experimenter then showed each participant how to use and navigate around their given presentation slides on Microsoft PowerPoint. Participants were able to ask questions about the experiment. Observation notes were made by the experimenter, who sat at the back of the room, throughout the experiment. Participants were allowed to ask questions relating to PowerPoint, whilst direct help which may influence the teams' decisions were unanswered. At the end of the experiment, participants were given a set of post-task questionnaires to complete. They were also asked to speak English during the experiment at all times and were all paid after they have completed the experiment.

3 Dependent Variables

The analysis of this experiment as divided into three parts. These are 'SMMs development, 'body movement', 'performance' and questionnaire.

The first two parts were mainly video analysis for both verbal and non-verbal communication during the experiment. The coding for shamed mental models

development was adapted from Bristol [2]. This was further divided into two other sections, one on shared mental models and team decision-making, another is mainly based on how partners navigate each other around during the experiment. The final part on performance was gathered from properties selected by participants at the end of the task.

SMMs development. The first set of coding was used to analyze conversations and interactions within a team during the experiment. It was also used to identify the stages of development of the SMMs. For example these were; sharing/initiating plans, sharing/initiation evaluation, questioning/informing partner of own criteria, questioning/information of partner's criteria, requesting partner's opinion on actions/decisions, offering reasons behind decision and debate.

Communication and body movement codes were also used to analyze activities related to how participants within a team navigated each other around their own maps to ensure that the same specific points was being looked at an understood. This showed how participants verbalized spatial as well as textual information to their partners. It also showed how well participants understood the given information and what they thought were crucial facts in which they needed to share with their partners. For example these were; general navigation (left, right, square, center), reference to specific landmark, dividing screen into quadrants, giving specific driving directions using roads, giving directions in terms of north, south, east and west.

Body moment considered the conscious and subconscious body language used during interactions, even though these gestures could not be seen by their partners. This therefore focused mainly on the non-verbal communication aspect, taken from the video recordings. Example for coding includes; pointing at own computer screen, looking at the screen showing a copy of their partner's screen, other gesturing when talking to partner and turning towards the partition screen to talk to their partner on the other side during discussion. This coding allowed analysis to be done with respect to issues such as presence and articulation. For instance, in the condition where participants could see a copy of their partner's screen, the number of times they switched between the two computer screens was recorded.

These coding schemes were considered as part of the development SMMs, as partners were exchanging information and ensuring that they both had the same understanding of the maps or representation given.

Performance. At the end of the experiment, participants were asked to complete an answer sheet with their partners and finalize three properties they would like to rent. They were asked to list them in order of preference and the reasons for their choices. Because this scenario was designed for this experiment specifically, the marking scheme was also designed along side by taking into consideration all the criteria given to the participants. This marking scheme was then used to rank all ten properties in order and scores were given to each property. This enabled the final decisions made by all pairs to be measured and quantified to the same scale. Scores were then given to participants' three most preferred properties. However, if they managed to select their top three properties in the correct order according the marking scheme, they were awarded bonus points. These scores were then used to compare their performance between different pairs in both conditions. However, because the

marking scheme was designed especially for this therefore the scores were considered non-parametric.

Questionnaire. Subjective data such as satisfaction, ease of communication and the perceived difficulty of the task were taken from all the questionnaire responses from all the participants. Likert five-point rating scales were used throughout the questionnaire, which asked participants to rate their agreement to the given statements.

Finally, the data were coded into categories as mentioned which allowed further statistical analysis for participants from the two experimental conditions.

4 Results

Several statistical tests were carried out in order to find the differences in SMMS development, performance and satisfaction between the two experimental conditions.

SMMs development. Table 1 shows variables showing significant differences between the two conditions from paired-sample t-tests.

Table 1. SMMS Development Results

Variables	Condition with higher mean
Initiating/sharing of strategies ($t = 2.421$; $df = 21.65$; 2-tailed; $p<0.05$)	SR
Initiating/sharing of evaluation ($t = 2.639$; $df = 30$; 2-tailed; $p<0.05$)	SR
Giving instructions ($t = 2.39$; $df = 30$; 2-tailed; $p<0.05$)	SR
Debating ($t = 6.92$; $df = 21.19$; 2-tailed; $p<0.05$)	SR
Suggesting solutions ($t = 2.86$; $df = 30$; 2-tailed; $p<0.05$)	SR
Offering reasons ($t = 2.68$; $df = 30$; 2-tailed; $p<0.05$)	SR
Reading out loud ($t = 2.09$; $df = 30$; 2-tailed; $p<0.05$)	NSR

Body language. The only significance difference found was in gesturing when giving direction ($t = 2.06$; $df = 30$; 2-tailed; $p<0.05$). The NSR condition had a higher mean for this variable, meaning participants in this group gestured more when verbalizing information to their partners.

Performance. A Mann-Whitney test was performed on the scores given to all teams in both conditions.

Table 2. Performance Results

Condition	Minimum	Maximum	Mean	Std. Deviation
SR	25	120	68.75	28.878
NSR	45	120	88.13	32.176

Three pairs in the non-shared representation scored full marks of 120 whilst one pair from the shared-representation scored full marks. However, no significance difference was found.

Questionnaires. Responses from the questionnaires were also analyzed and compared between the two experimental conditions. T-tests were performed on the collected data. Significance differences were found in only two variables from the questionnaires.

Table 3. Questionnaire Results

Variables	Condition with higher mean
"I communicated with my partner articulately" ($t = 2.36$; $df = 30$; 2-tailed; $p<0.05$)	NSR
"I found it easy to navigate my partner to a location" ($t = 2.46$; $df = 25.42$; 2-tailed; $p<0.05$)	SR

Observation. In general all teams from both conditions started the task by studying each other's given criteria and narrowing down the choices of available properties to suit and compromise each other's preferences. Most pairs narrowed down their search by looking at all the text-based information given and ruling out properties which obviously did not satisfy their criteria. They then carried on to look at the reminding properties, often participants went back to the choices they had ruled out earlier on in the experiment in the cases where the perfect match was not found in the reminding pile.

Many participants in the SR condition had often written down a list of information their partners had and requests such as "Can you open the slide with the distance to the bus stop?" were observed throughout the experiment.

In the NSR condition, most pairs went through all the information available to each of them first. Specific questions were used to ask their partners when requesting or exchanging information. Participants in this condition were also forced to give directions to their partners to specific points on the maps, as they have different information on their slides. Directions were requested such as "starting from the yellow line, the motorway, from the left to right, can you direct me to where house A is?" or "if you were driving to house A, from the main junction at the bottom left of your map, can you explain how you would get to it?" These were less likely in the SR condition where partners could see the same pieces of information.

Overall, it was observed that SR teams often spent more time on more aspects of a property before making their final selections in comparison with the NSR condition.

5 Discussion

The three main hypotheses tested in this study were with regards to the overall and the development of SMMs within teams including levels of navigation and communication between partners, performance and the user experience between the

two experimental conditions. The data gathered from the experiment have been tested and some of the variables belonging to each category as shown in the results section have shown significance differences.

By eliminating face-to-face communication and direct sharing of resources, participants were forced to clearly communicate with their partners at various stages of the task. They also communicated about the organization of the task, roles, crucial steps and strategies in solving the problem. Because the given task relied heavily on the use of spatial information and navigation, participants were unable to simply read out information to their partners, and hence the importance of shared mental models.

It can be seen from the statistical tests performed that the SR group showed more SMMs development through their progressive conversations and decision making. Partners within this condition shared more evaluation, strategies and organization of the task as well as more debated backed up with reasons than those in the other group. This, in theory should allow the participants within the SR group to form 'clearer' shared mental models with their partners. From the analysis, participants in the SR group spent on average 96% of their total communications with their partners on SMMs development whilst only 69% of the time was spent on this by the other group. Participants in the NSR group spent 30% of their time navigating each other around as they needed to make sure they were able to combine their spatial information with each others' given they could not view these information themselves. It was also found that in the NSR condition, participants were strong to inform their partners of their current activities such as what they were looking at, what they were trying to find out for example. This was less important in the SR condition as participants could already see what their partners were looking at.

Much of the SMMs development in the SR condition came in the forms of strategic talk, discussions, evaluation and debate. This may be due to the fact that both partners felt they had an equal opportunity to find the solution as they both technically had all the information. On the other hand, this happened much less in the NSR. The SMMs development came in the forms of navigation for this condition. In the NSR condition, the overall team performance relied on how well partners navigated and communicated with each other as they have no shared visual representation to base their mental models on.

Overall, there was no difference between the performance and the overall difficulty rating of both conditions. All teams in both conditions were allowed the same amount of time to complete the task. Satisfaction levels on various aspects differ between the two conditions. Participants in SR group perceived the information given for the task to be easier to navigate and understand, whilst those in the NSR group had a higher level of satisfaction on how well they communicated with their partners.

By observation, it could be seen that the majority of the participants in the SR condition paid more attention to more aspects and focuses when making decisions. Participants from the NSR condition were forced to trust their partners' judgment and the information given to them by their partners. For example, one pair of participants in the NSR group started off their task with the participant who could see all houses telling his partner where they all were. His partner then mapped these houses onto the crime zones and made the decision himself, to eliminate those houses, which fell into the crime zones quickly. On the other hand, participants from the SR condition

preferred to study all houses considering all factors before they started the elimination process.

It can be concluded from this study that, if a virtual team needs to communicate briefly, precisely and make decisions promptly, then the use of shared visual representation between members did not seem beneficial on the performance outcome. It was also possible that participants from the SR condition were being overloaded by too much information available, which also included information of low importance and hence hindered them from focusing on main criteria, whereas without the shared representation, participants were forced to make quick judgments.

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