Association for Information Systems
AIS Electronic Library (AISeL)

ICIS 2010 Proceedings

International Conference on Information Systems (ICIS)

2010

REAL DECISIONS IN VIRTUAL WORLDS: TEAM COLLABORATION AND DECISION MAKING IN 3D VIRTUAL WORLDS

Alexander P. Schouten
VU University Amsterdam, aschouten@feweb.vu.nl

Bart van den Hooff
VU University Amsterdam, bhooff@feweb.vu.nl

Frans Feldberg
VU University Amsterdam, jfeldberg@feweb.vu.nl

REAL DECISIONS IN VIRTUAL WORLDS:

TEAM COLLABORATION AND DECISION MAKING IN 3D VIRTUAL WORLDS

Completed Research Paper

Alexander P. Schouten
VU University Amsterdam
Faculty of Economics and Business Administration
Knowledge, Information and Networks Research Group
De Boelelaan 1105
1081 HV Amsterdam
+31 (0)20 598 6061
aschouten@feweb.vu.nl

Bart van den Hooff
VU University Amsterdam
Faculty of Economics and Business Administration
Knowledge, Information and Networks Research Group
De Boelelaan 1105
1081 HV Amsterdam
+31 (0)20 598 6062
bhooff@feweb.vu.nl

Frans Feldberg
VU University Amsterdam
Faculty of Economics and Business Administration
Knowledge, Information and Networks Research Group
De Boelelaan 1105
1081 HV Amsterdam
+31 (0)20 598 6059
jfeldberg@feweb.vu.nl

Abstract

This study investigates how 3D virtual worlds (3DVWs) support team collaboration. Based on Media Synchronicity Theory, we pose that the shared environment and avatar-based interaction allowed by 3DVWs aid convergence processes in teams working on a decision making task, leading to increased shared understanding between team members. This increases performance of decision making teams. An experiment was conducted in which 70 teams of 3 participants had to decide on a spatial planning issue. The teams interacted using synchronous text-based chat, a 3D virtual decision room, or were present in the virtual environment mirroring the spatial planning task. Results revealed that in both the virtual decision room and the virtual environment shared understanding was higher than in the text-based chat condition. This led to higher task performance in terms of consensus, satisfaction, and cohesion. Our results show that 3DVWs offer potential for team collaboration over more traditional text-based collaboration technologies.

Keywords: Virtual Teams, 3D Virtual Environments, Virtual Worlds, Computer-Mediated Communication, Media Synchronicity Theory, Shared Understanding, Team Performance

Introduction

The growing globalization of markets and the increased geographical dispersion of organizations, together with increased IT capabilities to support collaboration, have led to a strong growth in academic and management attention for various forms of virtual team collaboration (Lipnack & Stamps, 2000; Tung & Turban, 1998). Up till now, most research in this area has focused on text- and data-based technologies that allow teams to work together virtually (Martin et al., 2004). In this study, we seek to explain how three-dimensional virtual worlds (3DVWs) may support virtual team collaboration and decision making. Thus, the research question guiding our research is: *How do 3D Virtual Worlds affect team collaboration and decision making*?

3DVWs are defined as "online electronic environments that visually mimic complex physical spaces, where people can interact with each other and with virtual objects, and communicate via avatars –a digital representation of themselves" (Bainbridge, 2007, p. 472). Well-known examples of 3DVWs are World of Warcraft (a 3DVW with a specific game element) and Second Life, an "open ended" 3DVW in that there is no purpose other than the purpose of the users (see Messinger et al., 2009, for a taxonomy and overview of different 3DVWs).

Compared to the text- and data-based technologies referred to above, 3DVWs have specific capabilities that may affect team collaboration (Davis et al., 2009; Schultze et al., 2008). First, interaction takes place in a shared environment where information is rendered visually in 3D. Second, in a 3DVW all team members are represented in the shared environment by means of an avatar, a 3D representation of the team members.

However, how these capabilities affect team collaboration and task performance has not been frequently studied. Previous research on 3DVWs tends to focus on individual processes, such as immersion and absorption, and individual information processing (Meijer et al., 2009; Kumar & Benbasat, 2004; Nichols et al., 2000), whereas little empirical research has focused on group interactions in 3DVWs. Furthermore, previous studies on collaborative virtual worlds tend to lack a theoretical rationale for how concepts such as immersion or social presence may influence collaboration in these environments (Biocca & Harms, 2002; Schuemie et al., 2001).

This study contributes to resolving both these shortcomings in previous research by providing an empirical exploration of group interactions in 3DVWs, and by using Media Synchronicity Theory (MST; Dennis et al., 2008) as a theoretical basis to explain how 3DVWs affect team collaboration and decision making. The first goal of this study is to answer our research question, and investigate how 3DVWs may affect team collaboration and decision making through the development of a shared understanding among team members. An empirical investigation of the value of 3DVWs for team collaboration and decision making is not only scientifically relevant since it adds to the scarce knowledge on group interaction in 3DVWs, but also serves a practical purpose in that it identifies the processes through which 3DVWs influence team collaboration and decision making, and provides management with guidelines on how to use derive optimum value from this 3DVWs as group support system. A second goal of the study is to test propositions derived from MST, thereby providing empirical support for the assumptions of MST. More specifically, we test how media capabilities specific to 3DVWs may affect the development of a shared understanding, and how this shared understanding, in turn, affects team collaboration and decision making. Testing these assumptions is an important contribution in the further development of MST.

In order to answer our question and realize these goals, we conducted an experiment to test whether the shared environment of 3DVWs may affect team collaboration. The experiment focused on a team decision process regarding the future destination of an open space within a specific neighborhood, comparing a "traditional" communication technology used for virtual team collaboration, synchronous text-based Computer-Mediated Communication (CMC), with synchronous interaction in a 3DVW. Before going further into the details of this experiment, however, we will first discuss the theoretical framework guiding our experiment.

Theory and Hypotheses

Media Synchronicity Theory

Media Synchronicity Theory (MST; Dennis et al., 2008) was originally developed in reaction to theories such as Media Richness Theory (MRT)(Daft & Lengel, 1986), which focuses on the "match" between task and media characteristics as a determinant of task performance. Where MRT contends that some media are inherently more appropriate for certain tasks, MST argues that tasks are composed of different communication processes which each require particular media capabilities. According to MST, any task that requires team collaboration (e.g., decision making, knowledge sharing or negotiation) consists of two fundamental communication processes (Weick, 1985): *conveyance* (the transmission of new information) and *convergence* (the discussion of preprocessed information). MST also distinguishes different media capabilities that are required to support both conveyance and convergence. Media capabilities are the potential structures provided by a medium which influence the manner in which individuals can transmit and process information. MST distinguishes the following media capabilities:

- Transmission velocity: the speed with which a medium can transmit a message.
- Parallelism: the number of simultaneous transmissions that can take place.
- Symbol sets: the number of ways in which information may be encoded in terms of multiple cues.
- Rehearsability: the extent to which a medium enables a message to be checked and edited before sending.
- Reprocessability: the extent to which a message may be reviewed and reexamined after the message has been received.

Conveyance in MST

Conveyance is the "transmission of a diversity of new information […] to enable the receiver to create and revise a mental model of the situation" (Dennis et al., 2008, p. 580). Conveyance refers to task-related information that needs to be shared and processed in order for each team member to create an individual understanding of a task. For example, in a decision making task, team members need to transmit the information each team member has to all other team members. Each team member then has to process this information in order to create a common frame of reference. For conveyance, media capabilities are required that allow for effective transmission of large quantities of new information and that allow for individual processing of that information in order to reach individual understanding of a task. Media that allow for greater reprocessability and rehearsability, and have a high degree of parallelism, are more appropriate for conveyance processes.

Convergence and synchronicity in MST

Convergence is "the discussion of preprocessed information about each individual's interpretation of a situation, not the information itself" (Dennis et al., 2008, p. 580). In other words, convergence is sharing the outcomes of the conveyance processes (i.e., the individual understanding) in order to reach shared understanding. Shared understanding refers to reaching a common understanding of a task and an understanding of each other's viewpoints (Weick, 1985). Shared understanding, in turn, is considered to be a prerequisite for effective team collaboration and decision making performance (Allen et al., 2008; Mathieu et al., 2000; Swaab et al., 2002; Thompson & Fine, 1999; Tindale & Kameda, 2000; Van Ginkel & Van Knippenberg, 2008). Convergence is strongly related to social-interactive aspects of team collaboration, such as cohesion and mutual trust among team members (Swaab et al., 2002). For example, in a decision task, team members need to share their individual understanding of the decision process and the decision to be made, and have to reach a shared understanding. This can only be achieved if the team members also deal with the social-interactive aspects of team interaction.

When a medium offers capabilities that support convergence, that medium is said to allow for *synchronicity*. Synchronicity is a shared pattern of coordinated synchronous behavior with a common focus that is needed to reach a shared understanding. A medium allows for high synchronicity when it has a high transmission velocity, offers more natural symbol sets, and has symbol sets better suited to the task at hand (Zigurs & Buckland, 1998), while at the same time having a lower degree of parallelism, rehearsability and reprocessability. Convergence and synchronicity are intimately related to shared understanding, collaboration and group decision making performance. Moreover, as we argue below, the unique capabilities of 3DVWs may support convergence processes. Therefore, this study focuses on the process of convergence as it emerges in 3DVWs. In the next section, we will discuss the specific convergence-related capabilities of 3DVWs as group decision support systems.

Convergence Capabilities of 3D Virtual Worlds

Compared to other online collaboration technologies, two sets of capabilities of current-day 3DVWs may especially support convergence processes: avatar-based interaction and the shared environment in which the interaction takes place. Both of these capabilities refer to the ways that information can be encoded and are therefore part of the general media capability of symbol sets as distinguished by MST. Our general proposition is that, through both avatar-based interaction and providing a shared environment, 3DVWs support synchronicity. Therefore, compared to traditional text-based CMC, 3DVWs are better suited to support convergence processes, and will therefore increase shared understanding among team members, leading to better collaboration and decision making.

To investigate these propositions, we conducted an experiment in which we compared traditional text-based CMC to interaction in a 3DVW. In order to distinguish between the effects that may be attributable to the avatar-based interaction and the effects possibly caused by the shared environment that is relevant to the task, we investigate two types of 3DVWs. First, we investigate interaction in a Virtual Decision Room (VDR) where participants are present in a 3DVW resembling a meeting room. Second, we investigate interaction in a Virtual Environment (VE) where participants are present in a 3DVW resembling the neighborhood about which the decision is to be made. In the following section, we will put forward our hypotheses.

Hypotheses

The capabilities that 3DVWs offer for avatar-based interaction are likely to create a sense of social presence (Short et al., 1976). Social presence is generally defined as the awareness of being present with others in a mediated environment combined with a certain degree of attention to the other's intentional, cognitive, or affective states (Harms & Biocca, 2004; Biocca & Harms, 2001). Avatar-based interaction offers a wide array of symbol sets: it is synchronous, uses text or voice interaction, and offers more cues than text-based interaction, such as gestures, avatar appearance and avatar behavior. These cue-rich forms of interaction may enhance social presence (Short et al., 1976). Moreover, avatar-based interaction may make communication more personal and more vivid than traditional CMC technologies, which may lead to increased attention towards others (Steuer, 1992). We expect that the rich interaction in 3DVWs will lead to higher levels of social presence in the VDR and VE condition than the CMC condition. Because both the VDR and VE condition offer avatar-based interaction, we expect social presence not to differ between these two conditions. This leads to our first hypotheses:

H1a. Social Presence will be higher in the VDR condition than in the CMC condition;

H1b. Social Presence will be higher in the VE condition than in the CMC condition.

H1c. Social Presence will not differ between the VE condition and the VDR condition.

Second, the shared environment in which the interaction takes place may create a sense of immersion, or the feeling of being enveloped and included in the environment (Schuemie et al.; Kim & Biocca, 1997). The immersive character of 3DVWs (i.e., users are actually in a virtual space) allows for interaction between users and between users and the environment by means of their avatar (Benford et al., 2001; Witmer & Singer, 1998). Users can move (or fly, or teleport) through the environment and may also interact with the environment in real time by modifying content or interacting with software agents. A higher the degree of stimuli and experiences offered by a 3DVW will lead to a stronger feeling of being immersed in the environment (Witmer & Singer, 1998). Therefore, we expect that immersion will be higher in both the VDR and VE condition because of the shared environment in which the participants are immersed. Moreover, we expect that the VE condition will have a higher level of immersion than the VDR condition. In the VE condition participants are immersed in a rich shared environment (i.e., the neighborhood) that offers more stimuli and experiences that resemble a real-life environment than the VDR condition, which shows a virtual meeting room. This leads to our second set of hypotheses:

H2a. Immersion will be higher in the VDR condition than in the CMC condition;

H2b. Immersion will be higher in the VE condition than in the CMC condition;

H2c. Immersion will be higher in the VE condition than in the VDR condition.

Our next hypotheses consider the development of shared understanding in both 3DVW conditions relative to the text-based CMC condition due to the higher levels of social presence and immersion that 3DVWs provide. First, we pose that the increased sense of social presence in 3DVWs is positively related to shared understanding. The sense of being with another in a shared space may enhance involvement and engagement with each other, leading to higher mutual attention (Biocca et al., 2003). Moreover, multiple cues may be used to transmit a message, which makes messages fast to encode and decode and thus support turn-taking, coordination and faster interactions. This is likely to allow for faster encoding of information which, in turn, supports synchronicity (Dennis et al., 2008, p. 586).

Second, immersion in the environment may also be related to shared understanding. A shared environment is likely to support convergence processes because participants are immersed in an environment that is task relevant. If the environment is task relevant, the environment offers symbol sets that teams may use to more effectively encode and decode information. For example, an avatar may point to a certain aspect of the environment to clarify a statement, or a team may choose to fly through the environment as a group to stimulate common understanding. This is likely to allow for faster encoding of information which, in turn, supports synchronicity (Dennis et al., 2008, p. 586). Therefore, interaction in a 3DVW will allow higher synchronicity because of the wider array of symbol sets offered by the shared environment, leading to increased shared understanding.

Both 3DVW conditions are likely to provide comparable levels of social presence (H1a and H1b). However, the VE condition will allow higher synchronicity than the VDR condition due to the higher level of immersion it provides in a task-relevant environment because the symbol sets offered by the virtual world match those of the decision task (H2c). Based on these arguments, we expect the higher levels of social presence and immersion in 3DVWs to lead to a higher level of shared understanding in these environments compared to the CMC condition. We therefore pose the following hypotheses:

H3a. Shared understanding will be higher in the VDR condition than in the CMC condition;

H3b. Shared understanding will be higher in the VE condition than in the CMC condition;

H3c. Shared understanding will be higher in the VE condition than in the VDR condition.

H4. (a) Social presence and (b) immersion will mediate the relationship between the three experimental conditions and shared understanding.

As noted above, shared understanding is positively related to decision making performance (Mathieu et al., 2000; Swaab et al., 2002). Group members are likely to process any information about the task at hand from a common viewpoint, which facilitates task performance, especially in decision making and negotiation tasks (Swaab et al., 2002; Thompson & Fine, 1999; Tindale & Kameda, 2000). Furthermore, shared understanding is an important prerequisite for positive group outcomes such as cohesion (Mohammed & Ringseis, 2001; Park, 2008) and other task performance measures. In sum, we expect shared understanding to be an important mediator in the relationship between the experimental conditions and task performance.

Task performance is generally defined in terms of efficiency, effectiveness, and satisfaction (Dennis et al., 2001). First, in our study, efficiency is defined as the time to reach a decision (Adams et al., 2005). Higher levels of synchronicity support the development of shared understanding because encoding and decoding can be done more efficiently. Therefore, we expect that efficiency will be higher when shared understanding is higher (Gabarro, 1990), leading to the following hypotheses:

H5a. Efficiency will be higher in the VDR condition than in the CMC condition;

H5b. Efficiency will be higher in the VE condition than in the CMC condition;

H5c. Efficiency will be higher in the VE condition than in the VDR condition;

Next, as our study focuses on shared decision making and our task has no correct answer, our measure of effectiveness is group consensus. Research shows that reaching consensus on a decision is generally harder in distributed settings than face-to-face settings (Fjermestad, 2004; Hedlund et al., 1998). The increased shared understanding due to the higher levels of synchronicity in 3DVWs may mitigate these effects. Shared understanding is therefore positively related to consensus, leading to the following hypotheses:

H6a. Consensus will be higher in the VDR condition than in the CMC condition;

H6b. Consensus will be higher in the VE condition than in the CMC condition;

H6c. Consensus will be higher in the VE condition than in the VDR condition;

Satisfaction is the third measure of task performance and is usually split into two dimensions: process satisfaction and outcome satisfaction (Chidambaram, 1996). Process satisfaction relates to the degree to which participants are content with the group process including procedural and relational aspects of the activity, member contribution, and participation (Green & Taber, 1980; Lowry et al., 2006). Outcome satisfaction is concerned with the overall satisfaction of the team members with the task outcomes, whether team members think results are valuable and effective, and whether the team members agree with the decision made (Cannon-Bowers et al., 1993; Chidambaram, 1996). The common frame of reference and the development of common beliefs and attitudes associated with shared understanding is likely to positively influence process and outcome satisfaction (Hinds & Weisband, 2003). Therefore, process and outcome satisfaction will be positively associated with shared understanding, leading to the following hypotheses:

H7a. Process satisfaction will be higher in the VDR condition than in the CMC condition;

H7b. Process satisfaction will be higher in the VE condition than in the CMC condition;

H7c. Process satisfaction will be higher in the VE condition than in the VDR condition;

H8a. Outcome satisfaction will be higher in the VDR condition than in the CMC condition;

H8b. Outcome satisfaction will be higher in the VE condition than in the CMC condition;

H8c. Outcome satisfaction will be higher in the VE condition than in the VDR condition;

To capture the formation of a group identity, we included a measure of cohesion (Hogg, 1992). Group cohesion is a sense of connection, unity, and attractiveness in a group and is an important prerequisite for further collaboration (Carron & Brawley. 2000; Hogg, 1992). Cohesion is the outcome of the group's process of working together (Yoo & Alavi, 2001). Shared understanding is an important prerequisite for the establishment of cohesion (Mohammed & Ringseis, 2001). Therefore, we pose the following hypotheses:

H9a. Cohesion will be higher in the VDR condition than in the CMC condition;

H9b. Cohesion will be higher in the VE condition than in the CMC condition;

H9c. Cohesion will be higher in the VE condition than in the VDR condition;

Finally, because we pose that shared understanding will mediate the relationship between experimental condition and task performance, we pose the following hypothesis:

H10. Shared understanding will mediate the relationship between the three experimental conditions and (a) efficiency, (b) consensus, (c) process satisfaction, (d) outcome satisfaction, and (e) cohesion.

Method

Participants

Participants were 210 undergraduate students in Business Administration. The participants received course credit in return for their participation. Participants ranged in age from 18 to 28 (M = 19.72, SD = 1.57) and 30% percent of participants were female. All participants used Instant Messaging and were familiar with text-based CMC. Forty-four participants indicated having used a virtual world, most notably World of Warcraft (n = 19), and Second Life (n = 11). Most participants who reported having used Second Life were not active users; only one participant indicated that he used Second Life 10 hours a week. Because the aim of the study is to investigate the effects of a 3D virtual world on group decision making, the group served as our unit of analysis. Therefore, all individual scores of group members were collapsed and all analyses are conducted at the group level.

Task

The task was a spatial planning problem in which the teams represented a neighborhood council making a decision about a development plan for their neighborhood. The neighborhood used for the task was a schematic representation of an existing urban neighborhood that consisted of a residential area, several office buildings, and small production and trade companies (see Figure 1). The development plan offered four alternatives for a vacant space in the neighborhood. The neighborhood council, which represented both residents and business, was to make a decision about one of the alternatives. Each alternative had several advantages and disadvantages for both business and residents but there was no best alternative. The advantages and disadvantages were presented to the teams in a mock-up article from a local newspaper that discussed the development plan. However, there was no predefined list of criteria on which the alternatives could be judged. Therefore, participants had not only to choose the best alternative, but also had to agree on the criteria on which to judge each alternative. All participants had access to the same information. The four alternatives were:

- A multifunctional sports centre with a fitness centre, a hall for indoor sports, an indoor swimming pool, and a wellness centre.
- A multifunctional centre with a theater, a movie theater, a community centre, day care, and several restaurants and bars.
- A shopping mall with a supermarket, department store, restaurants and bars, and several smaller shops such as dress stores.
- A combination of a green area (with a park, a children's farm, and a grassplot) and a parking garage.

In terms of Campbell's (1988) typology of complex tasks, our task has both multiple outcomes (the decision amongst the four alternatives) as well as multiple solution schemes (the teams had to decide which criteria to take into account into their decision). Therefore, the task classifies as a fuzzy task. According to Zigurs and Buckland's theory of task-technology fit (1998), such a task requires a high degree of communication support. Moreover, according to McGrath's group task circumplex, our task would classify as a judgment task, in which the group is seeking a preferred answer. Such tasks in which consensus should be attained, require a high degree of coordination and communication of 'social information', such as beliefs, attitudes, and values (Straus, 1999). Therefore, our task matches the goals of our experiment in that the task focuses on the convergence processes that are needed to reach shared understanding and does not focus on the conveyance and individual processing of new information.

Experimental Design

Seventy teams of three participants were randomly assigned to one of the following three conditions: a text-only CMC condition (n = 23), a Virtual Decision Room condition (VDR; n = 24) and a Virtual Environment condition (VE; n = 23). In the CMC condition groups interacted using a web-based java chat application similar to an Instant Messaging application. Participants could only use text-based chat to communicate. Team members were identified by their nicknames, which were generic names assigned to them by the chat application based on the gender of the participant. Participants were asked to live into their roles as neighborhood council members and were asked to consequently use their nicknames and not ask for the other team members' real name.

For the VDR condition we built a virtual meeting room in Second Life (see Figure 2). This was a small window-less meeting room containing only a table and chairs. Participants were identified with an avatar, a 3D digital representation of a human being (Bailenson et al., 2006). Participants were assigned a male or female avatar based on their gender. The avatars were of average attractiveness, and were uniformly dressed wearing a T-shirt and jeans. Groups communicated using the built in Instant Messaging application available in Second Life and could not communicate using audio. The avatars representing the participants could not leave the decision room until a decision was made.

For the VE condition a virtual neighborhood was built in Second Life. The virtual neighborhood was a 3D digital representation of the neighborhood about which the team was to make a decision (see Figure 1). The participants in the VE condition were assigned the same avatars as in the VDR condition and could also only communicate using the built in Instant Messaging application. Upon logging in, the participants' avatars were automatically transferred to the vacant space in the center of the neighborhood that represented the area about which they should make a decision. Participants were free to walk (or fly) around the neighborhood, but they could not leave the neighborhood until a decision was made.

Figure 1. The Virtual Environment (VE) condition showing a birds-eye view of the neighborhood and the decision space (the vacant space in the center).

Figure 2. The Virtual Decision Room (VDR) condition, including a lonely avatar.

Procedure

In the week prior to the actual experiment, all participants received a training session in the use of Second Life. In this session, which lasted an hour, participants learned the basic skills of movement and interaction. After the session was finished, participants were asked to sign up individually in a two-hour time slot. A random selection of time slots was presented to each participant in order to minimize the chance of participants already being acquainted.

Each experimental session consisted of three groups of three participants. At the beginning of each session, the nine participants were received in a dedicated instruction room where they received instructions on the experimental procedures and the decision making task. The participants were asked to read three documents: (1) general instructions about the experiment, (2) general information about the neighborhood and the decision task, and (3) the mock-up newspaper article discussing the available options in more detail. During the experiment, both instructions and the newspaper article were available on paper for each participant, so all participants had continuous access to all information about the decision task.

After the general instructions participants were randomly distributed across the three conditions. Participants were asked to take place in nine separate cubicles that were spread across different computer rooms. Participants were instructed to remain quiet and only communicate using the instant messaging applications. Each computer room was supervised by an instructor. All further instructions were provided on-screen.

Our study specifically focuses on convergence processes needed for successful team collaboration. We hypothesized that the shared presence in a virtual world would enhance shared understanding and group decision making. Therefore, the information that the teams received across conditions needed to be similar in order to control for any differences in conveyance processes. To make sure that any effects were due to this increased sense of shared presence and would not be caused by the mere availability of information in certain conditions, all participants saw a short movie about the neighborhood. This way, all effects would be due to the increased sense of presence and not due to, for example, information about the visual lay-out of the neighborhood. The movie was shot in Second Life and showed a bird's eye view of the neighborhood explaining the lay-out and different structures of the neighborhood. The participants saw the movie before the start of the decision task.

After viewing the movie, participants entered one of the three conditions. In the CMC condition groups logged in to the java-based chat application, displayed in a full-screen browser window. In the VDR and VE conditions the groups automatically logged into Second Life and could immediately begin the group discussion. A time limit was imposed on the groups; they were asked to make a decision within 30 minutes. After 25 minutes the teams received an on-screen warning that they should reach consensus within five minutes. When the time limit was exceeded, the teams were automatically logged out and redirected to the questionnaire. All groups, however, were able to reach consensus before the deadline. When a group reached consensus, they pressed a big red button. They were then logged out of the application and redirected to an online questionnaire. Finally, participants were debriefed in short and were asked not to communicate with others about the experiment. After the experiment finished, all participants were debriefed about the goal of the experiment.

Measures

Social presence and immersion

We used the 5-item co-presence scale of Harms & Biocca (2004) to measure social presence. One item ("During the discussing my team members' presence was obvious to me") was dropped from the scale because of a low item-total correlation due to a translations error.

We used three items to measure immersion based on the scale by Kim & Biocca (1997). Cronbach's alpha was .73. Scale items and factors scores for all scales are presented in the appendix. Unless otherwise indicated, all items were measured on a 5-point scale ranging from 1 (*completely disagree*) to 5 (*completely agree*).

Shared understanding and outcome measures

The four items used to measure shared understanding were taken from Swaab et al. (2002). The first two items measured the extent to which group members had a shared perception of the decision task. The last two items measured the extent to which the participants understood each other's viewpoints. In line with earlier research (see Dennis et al., 2001), performance is characterized by three major factors: efficiency, effectiveness, and satisfaction. First, efficiency was assessed using the time needed to complete the group discussion. Second, effectiveness was assessed by degree of consensus, because there was no single correct answer to the decision task. To assess group consensus, we asked participants to rate how much they agreed with their team's choice on a 7-point scale ranging from 1 (*completely disagree*) to 7 (*completely agree*). Third, we included two measures of satisfaction: satisfaction with the group process, and outcome satisfaction. To measure process satisfaction, we used four items that measured participants' attention to the task and perceived quality of the discussion, based on the measure by Lowry et al. (2006). To measure outcome satisfaction, we used the three items measure used by Swaab et al. (2002). Finally, we used the three items by Swaab et al. (2002) to measure group cohesion, but included an extra item ('I am happy to belong to my team') to capture the affective component of group cohesion. For all the factors used in our structural model, correlations, Cronbach's alphas, average variance extracted (AVE), and the composite reliabilities (CR) are provided in Table 1.

Table 1. Correlations between constructs used in the structural model

	M (*SD*)	CR	α	1	2	3	4	5	6	7	8	9
1 Condition (0 = CMC; 1 = VDR and VE)	0.67 (0.47)	1	1	1								
2 Social Presence	4.17 (0.30)	.90	.87	.18	.81							
3 Immersion	3.01(0.47)	.84	.74	.35*	.27*	.80						
4 Shared Understanding	4.27 (.041)	.90	.85	.41**	.43**	.44**	.83					
5 Consensus	6.63 (0.42)	1	1	.28*	.18	.31*	.52**	1				
6 Decision Time	19.26 (5.32)	1	1	-.05	.00	-.01	-.07	-.29*	1			
7 Process Satisfaction	4.35 (0.31)	.88	.75	.32**	.50**	.34**	.65**	.37*	.05	.80		
8 Outcome Satisfaction	4.52 (.031)	.88	.79	.33**	.37**	.28*	.78**	.68**	-.07	.68**	.84	
9 Cohesion	3.53 (0.40)	.87	.81	.25*	.36*	.60**	.47**	.37*	.01	.43**	.35*	.79

Note. $*p < .05$; $**p < .01$; $n = 70$; CR = Composite Reliability; CMC = text-based chat condition; VDR = Virtual Decision Room condition; VE = Virtual Environment Condition; For the structural model, the VDR and VE condition were collapsed in one group; The values on the diagonal are the squared root of the Average Variance Extracted (AVE).

Results

Experimental Satisfaction

To rule out the possibility that any of the effects were due to the fact that groups liked one condition more than the other, we assessed satisfaction with the experiment. We asked participants to indicate how much they liked participating in the experiment on a five-point scale ranging from 1 (*completely disagree*) to 5 (*completely agree*).

Overall, the groups liked participating in the experiment (M = 3.99, SD = 0.40). A univariate ANOVA revealed no differences among the three conditions, $F(2, 67) = 0.62$, $p = .545$, $\eta^2 = .02$[1].

Social Presence and Immersion

Table 2 compares the means of all mediating and outcome variables across the three conditions. In order to test the first two hypotheses, we tested whether social presence and immersion differed between the three conditions. Social presence did not differ between the three conditions, $F(2, 67) = 2.16$, $p = .123$, $\eta^2 = .06$, which leads us to reject hypotheses 1a and 1b. Immersion, however, was different between the three conditions, $F(2, 67) = 3.46$, $p = .037$, $\eta^2 = .09$. Tukey's HSD post-hoc tests revealed that immersion was higher in both the VE and VDR conditions than in the CMC condition. Therefore, hypotheses 2a and 2b were confirmed, while hypothesis 2c is rejected.

Table 2: Outcome variables across the three conditions

	CMC	VDR	VE
	(n = 23)	(n = 24)	(n = 23)
	Mean (SD)	Mean (SD)	Mean (SD)
Social Presence	4.09 (0.34)	4.15 (0.25)	4.27 (0.28)
Immersion	2.81^a (0.43)	3.12^b (0.40)	3.11^b (0.47)
Shared Understanding	4.02^a (0.40)	4.31^b (0.36)	4.47^b (0.34)
Decision Time	19.65 (5.97)	19.67 (4.94)	18.43 (5.18)
Consensus	6.46 (0.49)	6.74 (0.37)	6.70 (0.43)
Process Satisfaction	4.21^a (0.32)	4.41^b (0.24)	4.43^b (0.32)
Outcome Satisfaction	4.37^a (0.34)	4.58^b (0.28)	4.60^b (0.26)
Cohesion	3.39 (0.47)	3.64 (0.37)	3.56 (0.40)

Note. CMC = Computer-Mediated Communication condition, VDR = Virtual Decision Room Condition, VE = Virtual Environment condition. Different superscripts indicate significant differences among the three conditions, $p < .05$.

Shared Understanding

Results revealed a significant difference between the VDR and VE conditions and the CMC condition in degree of shared understanding (see Table 2), $F(2, 67) = 8.48$, $p = .001$, $\eta^2 = .20$. Therefore, our third hypothesis was partly confirmed. Being present in a virtual world enhances shared understanding, confirming hypotheses 3a and 3b. Being present in the decision space (the VE condition) does not add to shared understanding among team members compared to the VDR condition, disconfirming hypothesis 3c.

Outcome Measures

Of the four alternatives that the teams had to choose between, the multifunctional centre was chosen most often. 29 of 70 teams (41.4%) considered this option to be best. 23 teams (32.9%) chose the shopping mall as the best alternative. The sports centre and the combination of a park and a parking garage were each chosen by 9 teams as best alternative. Time needed to reach a decision ranged from 11 to 30 minutes (M = 19.26, SD = 5.33). Analysis

[1] η2 (eta squared) is a measure of effect size in ANOVA-models and is comparable to an R-square in regression models. It is calculated by the dividing the effect Sum of Squares with the sum of the effect Sum of Squares and the error Sum of Squares. Effect sizes range from 0 to 1. A guideline for interpretation of the effect size for experimental research is that .01 indicates a small effect size, .09 a medium effect size, and .25 a large effect size (Tabachnick & Fidell, 2007).

revealed no differences in time to reach consensus between the three conditions, $F(2, 67) = 0.40$, $p = .671$, $\eta^2 = .01$. Therefore, hypothesis 5 was rejected.

Overall, group consensus as measured by the 7-point scale was high ($M = 6.63$, $SD = 0.43$). The difference in consensus between the three conditions just failed to reach significance, $F(2, 67) = 2.88$, $p = .063$, $\eta^2 = .08$. Tukey's HSD post-hoc tests revealed a marginally significant difference between the CMC and the VDR and VE conditions, $p = .073$. Therefore, hypothesis 6a and 6b were marginally supported, while hypothesis 6c was rejected.

Both the VDR and VE condition scored significantly higher than the CMC condition on both process satisfaction, $F(2, 67) = 3.87$, $p = .026$, $\eta^2 = .10$, and outcome satisfaction, $F(2, 69) = 4.31$, $p = .017$, $\eta^2 = .11$. Therefore, hypotheses 7a and 7b and hypotheses 8a and 8b were supported while hypothesis 7c and hypothesis 8c were rejected. Finally, the difference in cohesion across conditions was not significant, $F(2, 67) = 2.49$, $p = .091$, $\eta^2 = .07$. Therefore, hypothesis 9 was rejected.

The Mediating Role of Shared Understanding

The fourth hypothesis predicted that social presence and immersion would mediate the relationship between experimental conditions and shared understanding and our last hypothesis (H10) stated that shared understanding, in turn, would mediate the relationship between condition and the outcome measures. We tested these propositions with Partial Least Squares (PLS) modeling using SmartPLS (Ringle et al., 2005). We bootstrapped the resulting model to test the significance of the path coefficients using 200 bootstrap samples. As our previous results revealed no differences between the VDR and VE conditions on any of the outcome variables, we collapsed the VDR and VE condition and compared both conditions simultaneously with the CMC condition. The PLS model is shown in Figure 3. We performed Sobel tests to assess mediation (Sobel, 1982).

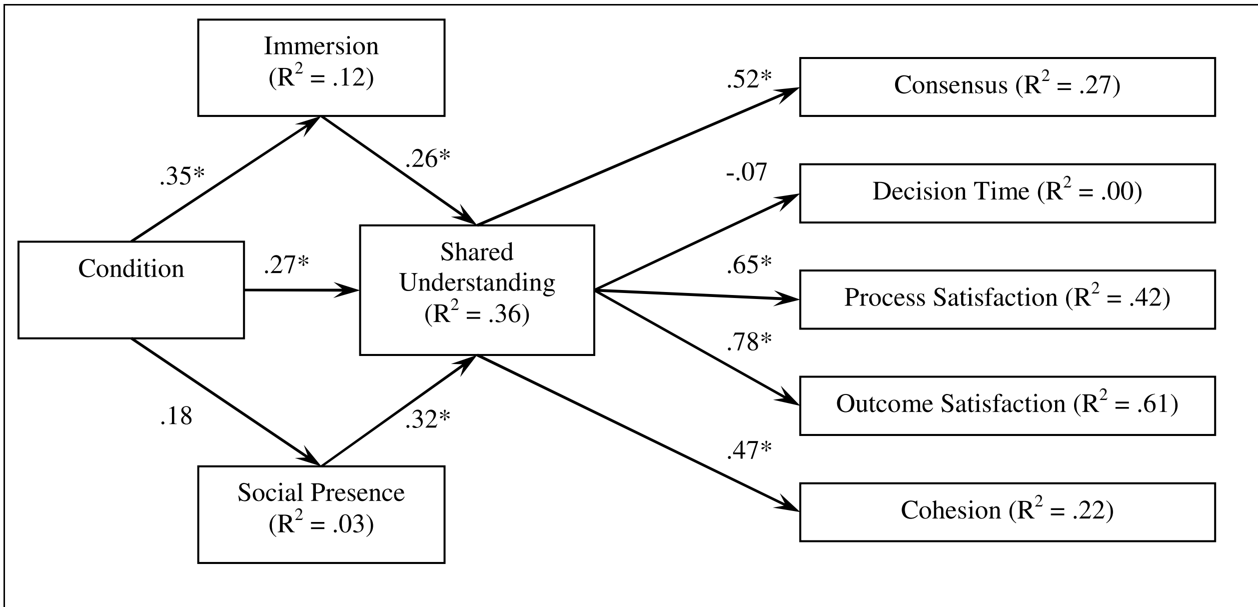

Figure 3. PLS Results. ***Note.*** **$*p < .01$**

Immersion mediated the relationship between experimental condition and shared understanding, $z = 2.62$, $p = .009$, thereby confirming hypothesis 4a. The mediating effect of social presence, however, was not significant, $z = 1.53$, $p = .127$. Therefore, hypothesis 4a was supported, while hypothesis 4b was rejected. The direct effect of experimental condition on shared understanding after controlling for social presence and immersion remained significant, $\beta = .267$, $p < .001$, suggesting partial mediation.

Our final hypothesis posed that shared understanding would mediate the relationship between experimental condition and the dependent variables. To test this hypothesis, we conducted Sobel tests of the mediating effects using the total effect (i.e., the sum of the direct and indirect effects) of experimental condition on shared understanding and the separate effects of shared understanding on each of the dependent variables. Shared understanding significantly mediated the relationships between experimental condition and the dependent variables, all z's > 4.47, all p's < .001, except for efficiency, $z = -0.72$, $p = .470$. None of the direct relationships between condition and the dependent variables remained significant when shared understanding was added to the model. Therefore, hypothesis 10a (efficiency) was rejected, while hypotheses 10b-e were supported. Moreover, the results of the mediation analysis also showed that the total indirect effects of condition on consensus, process satisfaction, outcome satisfaction, and cohesion were significant. Although the ANOVA results showed no significant difference in consensus and cohesion between conditions, the significant results of the mediation analysis suggest that cohesion and consensus are still positively affected by being in a virtual environment via shared understanding, thereby providing partial support for hypotheses 6a and 6b and hypotheses 9a and 9b.

Assessing Common Method Variance

Because all our mediating and dependent variables were collected concurrently, common method variance is a potential threat to internal validity of our results. Common method variance may result in inflated relationships between our variables because of common variance derived from the measurement instruments, leading to an increased risk of Type I errors. Based on Podsakoff & Organ (1986), we assessed common method variance in two ways. First, we used Harman's one factor test to check for a single factor explaining a majority of the variance. We conducted a principal component analysis containing all manifest items. Eight factors explained 78% of the total variance, with the first factor explaining 34%, so no single factor explained a majority of the variance in our constructs. Next, we used the procedure explained by Liang et al. (2007) to correct for common method bias in PLS modeling. All paths in our model stayed significant when the common method factor was introduced. None of the path coefficients of the structural model before the common method factor was introduced were significantly different from the path coefficients of the structural model after the common method factor was introduced. On average, the common method factor explained 12% of the variance in each indicator.

Discussion

In general, our results provide support for our hypotheses. Compared to text-based CMC, 3DVWs led to higher levels of shared understanding in decision making teams. Moreover, shared understanding significantly mediated the effect of 3DVWs on consensus, process and outcome satisfaction, and cohesion. However, we failed to uncover any differences between the VDR condition and the VE condition, which was contrary to our expectations. Moreover, no significant effect on decision time was found. Finally, our manipulation checks did show that teams perceived the conditions to differ with respect to immersion, but the results partially contradicted our expectations. The implications of these findings are discussed below.

Our results offer support for several of the propositions put forward by MST. First, we showed that communication media with more natural symbol sets better support convergence processes than communication media with less natural symbol sets. Compared to text-based interaction, shared understanding was higher in the VDR condition. Therefore, the wider array of symbol sets and richer interaction offered by avatar-based interaction may support convergence processes in the interaction, thereby facilitating shared understanding. Second, shared understanding fully mediated the effects of 3DVWs on team collaboration and task performance. Shared understanding is seen as an important mediating process in attaining task performance, not only by MST, but by a wide range of theories (Dennis et al. 2008; Mathieu et al., 2000; Thompson & Fine, 1999). Our study showed that also in virtual team collaboration, shared understanding is an important prerequisite for effective team collaboration and decision making.

There was no difference in shared understanding between the VDR condition and the VE condition. We posed that the shared environment in which the decision took place would aid convergence processes leading to increased shared understanding and team performance. However, this hypothesis was rejected. An explanation may be that our VE condition did not offer sufficient task relevant symbol sets to support convergence. More information might need to offer more information than just the mere presence of being in a relevant environment. Although the neighborhood itself and the vacant decision space in the centre of the neighborhood were visualized in the VE conditions, the VE condition could not visualize each of the four alternatives. This could mean that the environment provided in the VE condition was insufficiently task relevant. Had we visualized each option in the neighborhood, participants would actually be able to view each option, which could have led to better decision making. However, this would also have allowed the participants in the VE condition to better reprocess the information about each decision option than the participants in the text-based CMC and the VDR condition. Because reprocessability is related to conveyance processes, we would not have known if any effects were due to convergence or conveyance processes.

This may have important consequences for MST. According to MST, symbol sets that are suited to the content of a message have a greater capacity to support synchronicity, which is needed for convergence processes. However, relevant symbol sets may also support conveyance processes because new information can be better transmitted and processed among group members. For example, a team member may explain the consequences of a building project using a 3D model. Currently, symbol sets in MST are only said to improve synchronicity, thereby supporting convergence processes. The media capability of symbol sets is rather a broad category in MST which could support both convergence and conveyance processes. More natural symbol sets that are required for interpersonal interaction might indeed add to synchronicity and therefore support convergence processes, while symbol sets suited to the content of a message might support both convergence and conveyance processes. Future research could test these propositions in order to further clarify the role of symbol sets in attaining convergence and conveyance.

A related suggestion for further research into 3DVWs would be to investigate the effects of the shared visual environment on conveyance processes. For example, 3DVWs allow new information to be presented visually, and might also be used to alter visual information in real time, for example by including simulation models. The current generation of popular 3DVWs allows for some dynamic interaction with the environment, but advanced techniques, such as real-time 3D modeling or the use of simulation models are extremely limited. This, however, is likely to change in the future (Davis et al., 2009). Research on immersive 3D environments has shown us that these technologies indeed may support information processing (Meijer et al., 2009), but it would be an interesting avenue to investigate the combined effect of presenting information visually while at the same time being present in the environment with other team members.

The results concerning the influence of social presence and immersion were partially contrary to expectations. We expected that the rich interaction in 3DVWs would lead to higher levels of social presence in the VDR and VE condition than the CMC condition. Because both the VDR and VE condition offer avatar-based interaction, we expected social presence not to differ between these two conditions. A possible explanation for the lack of significant differences between the 3DVW conditions and the CMC condition might be that in all conditions, participants communicated via typed text. Literature on the use of voice in virtual worlds interaction suggest that, in spite of technical problems and user preference for text-based communication, voice communication could indeed lead to different perceptions of social presence (Wadley & Gibbs, 2010). Another explanation may be that text-based CMC technologies, such as Instant Messaging, are household technologies, especially among young people. It has become a rather common way of interacting, and a very direct one. Therefore text-based CMC may create feelings of social presence as well as avatar-based interaction does. The lack of significant differences might also be attributed to a measurement problem: our measure of social presence might be too crude to capture the added effect of avatar interaction. It is entirely possible to be aware of others while not actually seeing them. Indeed, the score on social presence measure for the CMC condition was 4.08 on a five-point scale, well above the mid-point. In future research, it would be better to try to capture social presence with a measure which is better related to the propositions made by MST. For example, one could ask whether participants were able to convey multiple cues and experienced receiving them or social presence could also be observed by conducting content analysis of use of multiple cues in avatar-based interactions. Finally, the fact that the participants could not choose own avatar may be a very likely explanation for the lack of social presence, due to a lack of identification with avatars. This is an issue that should be pursued in future research, in which a comparison can be made between a condition in which participants choose their own avatars and one in which they do not.

Our results confirmed that immersion was higher in both the VDR and VE than the CMC condition. However, we found no differences in immersion between the VDR and VE conditions. Again, an explanation for this may be because of our measure of immersion. Our measure of immersion was a general measure of immersion in a virtual world. We did not specifically ask participants if they felt they were immersed or involved in the neighborhood the decision was about. In their discussion about the concept of presence, Witmer & Singer (1998) distinguish between immersion and involvement, with involvement being "focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities and events in the environment" (Witmer & Singer, 1998, p. 227). Presence thus not only involves immersion in an environment, but also attention to relevant stimuli in the environment. In this experiment, this would mean that the respondents would not only be immersed in the virtual world, but also involved in the virtual world, meaning that they are attentive to relevant cues that the neighborhood offers that may help them in the decision task. Future research might want to use this multidimensional conceptualization of presence instead of only focusing on immersion, because this would most likely better capture the value that relevant symbol sets would have for supporting shared understanding.

Our PLS analysis showed that immersion only partially mediated the relationship between the experimental conditions and shared understanding. Therefore, mediating factors other than social presence and immersion may play a role in explaining the effects of a shared environment and avatar-based interaction on shared understanding. Compared to text-based CMC, avatar-based interaction is not only characterized by enhanced social presence, but also by increased anonymity, interactivity (Kohler et al., 2009) and increased possibilities for self-presentation, that is, the "potential to make more malleable the impression one is able to make" (Walther, 1996, p. 20). These characteristics, among others, may also explain the increase in shared understanding in 3DVWs compared to text-based CMC interactions. Moreover, as noted above, involvement in the virtual world may also explain the effect of 3DVWs on shared understanding. Finally, perceived interactivity with the shared environment may also be enhanced by the opportunities that 3DVWs offer to create, change and move objects in the environment and this may therefore also be a factor of influence (Davis et al., 2009). Such interaction in itself is also likely to influence individual and shared understanding of the task. Future research should identify more dimensions of both avatar interaction and shared environment, and empirically test the influence of these dimensions on shared understanding.

Finally, our results revealed no difference in time needed to make a decision between the three conditions. An explanation could be that, although 3DVWs support decision making, the virtual world distracts from the decision process, thereby negating the effect of heightened synchronicity. Another explanation for could be that our teams only had 30 minutes to reach a decision. The time constraint could have pushed teams in all conditions to make a fast decision. It could be that significant results would have been found had there been no time restriction on team interactions. Moreover, it should be noted that in all conditions, participants communicated via typed text, which means that although the symbol sets differed, the rate of exchanging information could largely be the same.

It should also be noted that time was the only "objective" measure of performance in our study, the others were all self-reported ones. In future research, it might be valuable to include more objective measures of performance, such as decision quality in relation to respondents' own criteria. On the other hand, objective performance is only one of the outcome factors that measure performance in shared decision making processes. Also, we followed MST, in which communication performance is defined as reaching a shared understanding, which justifies a focus on subjective performance.

Conclusions

Our study investigated how the avatar-based interaction and the shared environment of a 3DVW may support team collaboration and decision making. To our knowledge, our study is one of the first to empirically investigate the effects of shared 3DVWs on team collaboration. Moreover, our study provides empirical evidence for the MST, specifically for the proposition that natural symbol sets support synchronicity and the resulting shared understanding. Our study offers some implications for both theory and practice. First, we feel that avatar-based interaction and the shared environment of 3DVWs are the most important capabilities of 3DVWs compared to other collaboration technologies. These capabilities provide a useful distinction to further investigate the role of 3DVWs in team collaboration. Second, we showed symbol sets in MST seem to play an important role in achieving synchronicity, but the exact way in which symbol sets support convergence and conveyance processes needs to be investigated further. Third, 3DVWs should not only be considered as a distinct phenomenon with its own research focus. Rather, research in 3DVWs may be used to test propositions put forward by other theories, such as MST.

Finally, our study shows that 3DVWs have the capacity to support team collaboration, which is an interesting avenue for further research, but also has practical implications. Our results show that 3DVWs indeed support team collaboration and decision making. Avatar-based interaction in a 3DVW led to higher levels of consensus, satisfaction, and cohesion among group members than traditional text-based CMC. Therefore, 3DVWs may support remote collaborative work. Not only do 3DVWs offer the same capabilities of other collaboration technologies, such as synchronous text-based or audio-visual interaction independent of time and place, but the capabilities of 3DVWs may further support team collaboration beyond that functionality. Moreover, we did not find any difference between the VDR and VE condition. Although our findings are tentative, if future research would also shows that avatar-based interaction is enough to trigger shared understanding, then organizations not need create expensive virtual worlds. Rather, a simple virtual decision room may be enough to support team collaboration and decision making.

Appendix. Scale Items and Reliabilities

Scale Items	Factor Loadings
Social Presence	
During the discussion I was aware of my team members	.68
During the discussion my team members were aware of me	.69
During the discussion my presence was obvious to my team members	.88
During the discussion my team members caught my attention	.87
During the discussion I caught my team members' attention	.88
Immersion	
During the discussion, I felt like being present in the virtual environment	.84
My senses were completely engaged during the experience	.65
During the discussion, I felt I was in the world the system created	.91
Shared understanding	
The members of my team were on par with each other	.87
The members of my team were at one about the decision	.82
The members of my team had the same view of the problem	.90
The members of my team understood each other's arguments	.73
Process satisfaction	
My team has put forward good quality ideas during the discussion	.83
The decision process went well	.76
My team has exchanged enough information to reach a correct decision	.80
My team was focused on the task	.82
Outcome satisfaction	
I accept the outcome of my team's decision	.78
I think we have made the right decision	.84
I am satisfied with the result of our group decision	.88
Cohesion	
There are a lot of similarities between the members of my team	.77
This team is a unity	.74
I'm happy to belong to my team	.83
I feel connected with my team	.79

References

Adams, S. J., Roch, S. G., and Ayman, R. 2005. "Communication Medium and Member Familiarity: The Effects on Decision Time, Accuracy, and Satisfaction," *Small Group Research* (36:3), pp. 321-353.

Bailenson, J. N., Yee, N., Merget, D., and Schroeder, R. 2006. "The Effect of Behavioral Realism and Form Realism of Real-Time Avatar Faces on Verbal Disclosure, Nonverbal Disclosure, Emotion Recognition, and Copresence in Dyadic Interaction," *Presence: Teleoperators & Virtual Environments* (15:4), pp. 359-372.

Bainbridge, W. S. (2007). "The Scientific Research Potential of Virtual Worlds," *Science* (317:5837), pp. 472-476.

Benford, S., Greenhalgh, C., Rodden, T. and Pycock J. 2001. "Collaborative Virtual Environments," *Communications of the ACM* (44:7), pp. 79-85.

Biocca, F., Harms, C., and Burgoon, J. K. 2003. "Toward a More Robust Theory and Measure of Social Presence: Review and Suggested Criteria," *Presence: Teleoperators and Virtual Environments* (12:5), pp. 456-480.

Biocca, F., and Harms, C. 2002. *Defining and Measuring Social Presence: Contribution to the Networked Minds Theory and Measure*, Media Interface and Network Design (M.I.N.D.) Labs, Dept. of Telecommunication, Michigan State University, MI.

Campbell, D.J. 1988. "Task Complexity; A Review and Analysis," *The Academy of Management Review* (13:1), pp. 40-52.

Cannon-Bowers, J.A., Salas, E., and Converse, S.A. 1993. "Shared Mental Models in Expert Team Decision Making," in *Current Issues in Individual and Group Decision Making*, N.J. Castellan, Jr. (ed.), Hillsdale, NJ.: Erlbaum, pp. 221-246.

Carron, A. V., and Brawley, L. R. 2000. "Cohesion: Conceptual and Measurement Issues," *Small Group Research* (31:1), pp. 89-106.

Chidambaram, L. 1996. "Relational Development in Computer-Supported Groups," MIS Quarterly (20:2), June, pp. 143-163.

Daft, R. L.,and Lengel, R. H. 1986. "Organizational Information Requirements, Media Richness and Structural Design," Management Science (32;5), pp. 554-569.

Davis, A., Murphy, J., Owens, D., Khazanchi, D., and Zigurs, I. 2009. "Avatars, People, and Virtual Worlds: Foundations for Research in Metaverses," *Journal of the Association for Information Systems* (10:2), pp. 91-117.

Dennis, A.R., Fuller, R.M. and Valacich, J.S. 2008. "Media, Tasks and Communication Processes: A Theory of Media Synchronicity," *MIS Quarterly* (32:3), September, pp. 575-600.

Dennis, A.R., Wixom, B.H. and Vandenberg, R.J. 2001. "Understanding Fit and Appropriation Effects in Group Support Systems via Meta-Analysis," *MIS Quarterly* (25:2), June, pp. 167-193.

Fjermestad, J. 2004. An Analysis of Communication Mode in Group Support Systems Research," *Decision Support Systems* (37:2), 239-263.

Gabarro, J. J. 1990. "The Development of Working Relationships," in *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work*, J. Galegher, R. E. Kraut, and C. Egido (eds.), Hillsdale, NJ: Lawrence Erlbaum, pp. 79-109.

Green, S. G. and Taber, T. D. 1980. "The Effects of Three Social Decision Schemes on Decision Group Processes," *Organizational Behavior and Human Performance* (25:1), pp. 97-106.

Harms, C., and Biocca, F. 2004. "Internal Consistency and Reliability of the Networked Minds Social Presence Measure," in *Seventh Annual International Workshop: Presence 2004*, M. Alcaniz and B. Rey (eds.), Valencia: Universidad Politecnica de Valencia.

Hedlund, J., Ilgen, D. R., and Hollenback, J. R. 1998. "Decision Accuracy in Computer-Mediated Versus Face-to-Face Decision-Making Teams," *Organizational Behavior and Human Decision Processes* (76:1), pp. 30-47.

Hinds, P. J., and Weisband, S. P. 2003. "Knowledge Sharing and Shared Understanding in Virtual Teams," in *Virtual Teams That Work: Creating Conditions for Virtual Team Effectiveness*, C. B. Gibson and S. G. Cohen (eds.), New York: Wiley, pp. 21-36.

Hogg, M.A. 1992. *The Social Psychology of Group Cohesiveness: From Attraction to Social Identity*, New York: New York University Press.

Kahai, S., Carroll, E., and Jestice, R. 2007. "Team Collaboration in Virtual Worlds," *SIGMIS Database* (38:4), pp. 61-68.

Kim, T., and Biocca, F. 1997. "Telepresence via Television: Two Dimensions of Telepresence May Have Different Connections to Memory and Persuasion," *Journal of Computer-Mediated Communication* (3:2), Available from http://jcmc.indiana.edu/vol3/issue2/kim.html

Kohler, T., Matzler, K., and Fuller, J. 2009. "Avatar-Based Innovation: Using Virtual Worlds for Real-World Innovation," *Technovation* (29:6-7), pp. 395-407.

Kumar, N., and Benbasat, I. 2004. "The Effect of Relationship Encoding, Task Type, and Complexity on Information Representation: An empirical evaluation of 2D and 3D line graphs," *MIS Quarterly* (28:2), June, pp. 255-281.

Liang, H., Saraf, N., Hu, Q., and Xue, Y. 2007. "Assimiliation of Enterprise Systems: The Effect of Institutional Pressures and the Mediating Role of Top Management," *MIS Quarterly* (31:1), pp. 59-87.

Lipnack, J., and Stamps, J. 2000. *Virtual Teams: Working Across Boundaries with Technology*, New York: Wiley.

Lowry, P. B., Roberts, T. L., Romano, N. C., Cheney, P. D., and Hightower, R. T. 2006. "The Impact of Social Presence on Small-Group Communication: Does Computer-Mediated Communication Make a Difference?," *Small Group Research* (37:6), pp. 631-661.

Martins, L. L., Gilson, L. L., and Maynard, M. T. 2004. "Virtual Teams: What do we Know and Where do we Go From Here?," *Journal of Management* (30:6), pp. 805-835.

Mathieu, J., Heffner, T. S., Goodwin, G. F., Salas, E. and Cannon-Bowers, J. A. 2000. "The Influence of Shared Mental Models on Team Process and Performance," *Journal of Applied Psychology* (85:2), pp. 273-283.

Meijer, F., Geudeke, B. L., and Van den Broek, E. L. 2009. "Navigating through Virtual Environments: Visual Realism Improves Spatial Cognition," *Cyberpsychology and Behavior* (12:5), pp. 517-521.

Messinger, P. R., Stroulia, E., Lyons, K., Bone, M., Niu, R. H., Smirnov, K., and Perelgut, S. 2009. "Virtual Worlds - Past, Present, and Future: New directions in Social Computing," *Decision Support Systems* (47:3), pp. 204-228.

Mohammed, S. and Ringseis, E. 2001. "Cognitive Diversity and Consensus in Group Decision Making: The Role of Inputs, Processes, and Outcomes," *Organizational Behavior and Human Decision Processes* (85:2), pp. 310–335.

Nichols, S., Haldane, C., and Wilson, J. R. 2000. "Measuring Presence and its Consequences in Virtual Environments," *International Journal of Human-Computer Studies* (52:3), pp. 471-491.

Podsakoff, P. M., and Organ, D. W. 1986. "Self-Reports in Organizational Research: Problems and Prospects," *Journal of Management* (12:4), pp. 531-544.

Ringle, C. M., Wende, S., and Will A. 2005. *SmartPLS 2.0 (beta)*, available from http://www.smartpls.de.

Schubert, T. 2009. "A New Conception of Spatial Presence: Once Again, With Feeling," Communication Theory (19:2), pp. 161-187.

Schuemie, M. J., Van der Straaten, P., Krijn, M., and Van der Mast, C. A. P. G. 2001. "Research on Presence in Virtual Reality: A survey," *Cyberpsychology and Behavior* (4:2), pp. 183-201.

Schultze, U., Hiltz, S. R., Nardi, B., Rennecker, J., and Stucky, S. 2008. "Using Synthetic Worlds for Work and Learning," *Communications of the Association for Information Systems* (22:19), pp 351-370.

Short, J., Williams, E., and Christie, B. 1976. *The Social Psychology of Telecommunications*, London: John Wiley.

Sobel, M. E. 1982. "Asymptotic Intervals for Indirect Effects in Structural Equations Models," in *Sociological methodology*, S. Leinhart (ed.), San Francisco: Jossey-Bass, pp. 290-312.

Steuer, J. 1992. "Defining Virtual Reality: Dimensions Determining Telepresence," *Journal of Communication* (42:4), pp. 73-93.

Straus, S. G. 1999. "Testing a Typology of Tasks: An Empirical Validation of McGrath's (1984) Group Task Circumplex," *Small Group Research* (30:2), pp. 166-187.

Swaab, R.I., Postmes, T., Neijens, P., Kiers, M.H. and Dumay, A. 2002. "Multiparty Negotiation Support: The Role of Visualization's Influence on the Development of Shared Mental Models," *Journal of Management Information Systems* (19:1), pp. 129-150.

Tabachnick, B. G., and Fidell, L. S. 2007. *Using Multivariate Statistics* (5th ed.), Boston: Pearson.

Thompson, L. and Fine, G.A. 1999. "Socially Shared Cognition, Affect and Behavior: A Review and Integration," *Personality and Social Psychology Review* (3:4), pp. 278-302.

Tindale, R.S. and Kameda, T. 2000. "'Social Sharedness' as a Unifying Theme for Information Processing in Groups," *Group Processes and Intergroup Relations* (3:2), pp. 123-140.

Tung, L. and Turban, E. 1998. "A Proposed Research Framework for Distributed Group Support Systems," *Decision Support Systems* (23:2), June, pp. 175-188.

Van Ginkel, W. and Van Knippenberg, D. 2008. "Group Information Elaboration and Group Decision Making: The Role of Shared Task Representations," Organizational Behavior and Human Decision Processes (105:1), pp. 82-97.

Wadley, G. and Gibbs, M. R. 2010. "Speaking in Character: Voice Communication in Online Virtual Worlds," in *Online Worlds: Convergence of the Real and the Virtual* (Human-Computer Interaction Series), W.S. Bainbridge (ed.), London: Springer-Verlag, pp. 187-200.

Walther, J. B. 1996. "Computer-Mediated Communication: Impersonal, Interpersonal and Hyperpersonal Interaction," *Communication Research* (23:1), pp. 3-43.

Weick, K. E. 1985. "Cosmos vs. Chaos: Sense and Nonsense in Electronic Contexts," *Organizational Dynamics* (14:2), pp. 51-64.

Witmer, B.G. and Singer, M.J. 1998. "Measuring Presence in Virtual Environments: A Presence Questionnaire," *Presence: Teleoperators & Virtual Environments* (7:3), pp. 225-240.

Yoo, Y. and Alavi, M. 2001. "Media and Group Cohesion: Relative Influences on Social Presence, Task Participation, and Group Consensus," *MIS Quarterly* (25:3), September, pp. 371-390.

Zigurs, I. and Buckland, B.K. 1998. "A Theory of Task/Technology Fit and Group Support Systems Effectiveness," *MIS Quarterly* (22:3), September, pp. 313-334.