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Investigating Multimodal Communication in Virtual Meetings: The Sharing of Dynamic Representations

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Abstract:

To manage distributed work, organizations increasingly rely on virtual meetings based on multimodal, synchronous communication technologies. However, despite technological advances, it is still challenging to coordinate knowledge through these meetings with spatial and cultural separation. Against this backdrop, we present a framework for investigating the sharing of dynamic representations of co-created knowledge during such meetings. We illustrate the detailed workings of the framework by analyzing how three software managers coordinated a project over a series of virtual meetings. Grounded in audio recordings of their oral exchanges and video recordings of their shared dynamic representation of the project's status and plans, our analysis shows how their interrelating of visual and verbal communication acts enabled effective communication and coordination. In conclusion, we offer theoretical propositions that explain how interrelating of verbal and visual acts based on shared dynamic representations enable communication repairs during virtual meetings. We argue that our proposed framework provides researchers with a novel and practical approach to investigate the complex data involved in virtual meetings based on multimodal, synchronous communication.

Keywords: Case Study, Virtual Meetings, Multimodal Communication, Communication Repairs, Knowledge Coordination.

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I. INTRODUCTION

The Internet and its associated technologies have made it easy to organize virtual meetings across the world and have allowed organizations to become increasingly distributed (Bergiel, Bergiel, & Balsmeier, 2008). However, with distribution, managers experience coordination challenges because of geographic, diversity, task distribution, and technology issues. Geographically dispersed activities require special attention to coordination due to time-zone differences (Massey, Montoya-Weiss, & Hung, 2003; Montoya-Weiss, Massey, & Song, 2001), locally situated knowledge (Sole & Edmondson, 2002), and lack of presence awareness (Espinosa, Slaughter, Kraut, & Herbsleb, 2007). National diversity may imply coordination difficulties related to communication routines (Maznevski & Chudoba, 2000), linguistic differences (Kayworth & Leidner, 2000), and weak interpersonal relationships (Kraut, Steinfield, Chan, Butler, & Hoag, 1999). Task distribution may further require special attention to task coupling (Ramesh & Dennis, 2002; Sakthivel, 2005; Sutanto, Kankanhalli, & Tan, 2011), task awareness (Espinosa et al., 2007), and inter-functional conflict resolution (Robey, Khoo, & Powers, 2000). Finally, technology mediation may imply coordination difficulties because of limited informal interactions (Fay, 2011; Herbsleb & Grinter, 1999) and differences in organizational identification across activities (Wiesenfeld, Raghuram, & Garud, 1999).

Defined as managing dependencies between activities, coordination is a key activity in any organization (Malone & Crowston, 1994). Coordination is intrinsically linked to performance (Johansson, Dittrich, & Juustila, 1999; Maznevski & Chudoba, 2000), and successful coordination is characterized by the integration and harmonious adjustment of individual activities toward the accomplishment of a larger goal (Singh, 1992) or simply by working together effectively (Malone & Crowston, 1991).

Effective coordination requires sharing knowledge, but research suggests it is difficult to exchange and share knowledge across distributed organizations (Cramton, 2001; Majchrzak, Malhotra, & John, 2005; Sole & Edmondson, 2002). Baba, Gluesing, Ratner, and Wagner (2004, p. 583) argue that “team members based in different cultures can bring together divergent bodies of knowledge whose integration yields new organizational capabilities, but only after they recognize both the existence and the validity of their differences”. Researchers have coined this the mutual knowledge (Cramton, 2001) or the situated knowledge problem (Sole & Edmondson, 2002). As a result, some scholars have suggested that geographically dispersed organizations should communicate differences through virtual meetings enabled by information technology (Majchrzak et al., 2005), focus on how different technologies offer distinct advantages and disadvantages for virtual meetings (Hertel, Geister, & Konradt, 2005), and explore ways to support interactions that are close to cross-organizational collaboration under co-located working conditions (Martins, Gilson, & Maynard, 2004). More specifically, Malhotra, Majchrzak, and Carman (2001) suggest that geographically dispersed organizations should promote shared understanding based on the rapid creation of context-specific transient information. This shared understanding can be achieved by developing “common-language” metaphors, through synchronous and frequent virtual interactions, and through timely and frequent discussions of new entries in knowledge repositories (Malhotra et al., 2001). In fact, Malhotra et al. suggest that “technology for knowledge management is less important than technology that allows knowledgeable people to collaborate” (Malhotra et al., 2001).

Existing research shows that there are important and persistent challenges related to knowledge sharing and coordination in distributed organizations and a need to further investigate how new and different forms of virtual meetings can improve it (Espinosa et al., 2007; Kanawattanachai & Yoo, 2007; Kotlarsky, van Fenema, & Willcocks, 2008; Malhotra et al., 2001; Malhotra & Majchrzak, 2012). Against this backdrop, our research increases our understanding of how knowledge may be created and shared through dynamic representations in multimodal, synchronous communication practices and of how such practices may enable coordination through virtual meetings in distributed organizations. Hence, we pose:

> **RQ:** *How does dynamic representation of co-created knowledge in multimodal communication affect coordination during virtual meetings?*

To address the research question, we propose a framework for investigating multimodal communication that involves sharing dynamic representations of co-created knowledge during virtual meetings. We illustrate the detailed workings of the framework by analyzing a series of meetings between three managers in a distributed software organization. The meetings were based on a combination of verbal communication based on teleconferencing and visual communication based on dynamic representation of the project’s status and plans in a shared mindmap.

Access to rich data, including audio recordings of the managers' oral exchanges, video recordings of their shared mindmapping, data from interviews with key stakeholders, archival data, and research notes from a site visit, allowed us to go beyond analyses of virtual interactions that mainly emphasize individual perceptions of knowledge coordination (Anderson, McEwan, Bal, & Carletta, 2007). Based on our analyses, we offer theoretical propositions that explain how multimodal communication with dynamic representations of co-created knowledge may support coordination in virtual meetings by enabling communication repairs. Moreover, we argue that the proposed framework provides researchers with a novel and practical approach to investigate the complex data involved in virtual meetings that involve multimodal, synchronous communication.

II. MEDIATED COMMUNICATION IN VIRTUAL MEETINGS

The manner in which distributed organizations use media influences how their members coordinate and share knowledge (Dennis, Fuller, & Valacich, 2008; Malhotra & Majchrzak, 2012). Bélanger and Watson-Manheim's (2006) study of mediated communication found complementary media enhanced knowledge sharing, which suggests that multimodal communication facilitates virtual meetings. Multimodality generally refers to the employment of more than one form of communication. In the case investigated in this study, it specifically refers to verbal communication through teleconferencing combined with visual communication through real-time collaborative modeling in a shared mindmap[1]. Oviatt (1999, p. 74) argues that:

> *well-designed multimodal systems integrate complementary modalities to yield a highly synergistic blend in which the strengths of each mode are capitalized upon and used to overcome weaknesses in the other. Such systems potentially can function more robustly than unimodal systems that involve a single recognition-based technology*.

Similarly, other research suggests multimodality may help manage situations of information overload (Edmunds & Morris, 2000; Sarter, 2006) that potentially lead to a loss of perspective and a greater tolerance of error (Eppler & Mengis, 2004).

Synchronicity in mediated communication may also positively influence knowledge coordination. Defining synchronicity as the ability to support individuals working together at the same time with a shared pattern of coordinated behavior, Dennis et al. (2008) argue that convergence processes (understanding the meaning of information) benefit from the use of media that facilitate synchronicity. Similarly, comparing synchronous and asynchronous text-based communication in a class setting, Hrastinski (2008) argues that an increase in the degree of synchronicity improved personal participation because it provided increased psychological arousal, motivation, and convergence on meaning. Taken together, these findings suggest synchronicity may help managers overcome the challenges related to coordinating knowledge in distributed organizations.

Several investigations of multimodal, synchronous communication have been conducted in the context of collaborative learning in small groups (Dillenbourg & Traum, 2006; Mühlpfordt & Stahl, 2007; Mühlpfordt & Wessner, 2005; Soller & Lesgold, 2003; Suthers et al., 2001; Çakir, Zemel, & Stahl, 2009). Çakir et al. (2009) summarize two broad categories of research approaches for investigating such mediated interactions. The first category (Avouris, Dimitracopoulou, & Komis, 2003; Soller & Lesgold, 2003) devises models of user actions performed across multimodal interaction spaces tailored to a specific problem-solving situation with idealized solution cases. The second category (Baker, Hansen, Joiner, & Traum, 1999; Dillenbourg & Traum, 2006; Jermann, 2002; Suthers et al., 2001) uses content analysis of user actions by combining theoretically informed coding schemes and statistical analyses to investigate specific aspects of collaborative work. However, Çakir et al. (2009) critique these studies' use of laboratory settings where actions are restricted in order to control variables and facilitate coding of utterances in a fixed ontology. Moreover, because temporal and semiotic relations are essential to understanding, sharing, and coordinating meaning across teams, they criticize the adopted research approaches for ignoring the complexity of relations among utterances and for moving the focus away from the flow and interactions involved in mediated communication. As a result, Çakir et al. (2009) draw on studies of interaction mediated by online text chat (Garcia & Jacobs, 1998; Garcia & Jacobs, 1999; O'Neill & Martin, 2003) to appropriate ethno-methodology and conversation analysis for investigating mediated group interactions at a micro-level (Psathas, 1995; Sacks, 1995; Ten Have, 1999). Yet, even though Çakir et al.'s (2009) study in this way supports in-depth analyses of virtual meetings, it shares limitations with the other available approaches:

- Existing approaches do not provide techniques for investigating audio modality as an integral part of multimodal synchronous communication practices; this is unfortunate because verbal communication arguably constitutes the backbone of most forms of virtual meetings.

[1] A mindmap is a diagram used to represent words, ideas, tasks, or other items linked to a central keyword or idea.

- Existing approaches are developed to investigate distributed collaboration to solve well-defined problems (e.g., involving middle-school math students); this context is, however, rather different from distributed organizations in which people typically work on complex and cognitive interdependent task with no clear measure of success.

In conclusion, while current research suggests multimodal, synchronous communication can help improve knowledge coordination in distributed organizations, we found no comprehensive approaches for investigating the role of dynamic representations in virtual meetings based on such technologies. Therefore, we designed this study to fill this void and to respond to calls for research into how collaborative tools that support dynamic representations can "facilitate the flow and creation of knowledge among individuals working on a complex, cognitive, interdependent tasks" (Kanawattanachai & Yoo, 2007, p. 800).

III. RESEARCH DESIGN

We adopted a case study approach for several reasons (Benbasat, Goldstein, & Mead, 1987; Yin, 2003): because our research is guided by a how question; because dynamic representation based on multimodal, synchronous collaboration is a contemporary phenomenon that needs further investigation in real-life contexts; and because, while dynamic representation can affect coordination and knowledge sharing in distributed organizations, this relationship is not well understood in virtual meetings. In addition, we had access to a case with unique and interesting characteristics (Yin, 2003), where teleconferencing was combined with dynamic representation of the project's status and plans during virtual meetings. The team's task was to finalize the development of the mindmapping tool they also used to support visual and dynamic representation in their meetings. We were thus able to investigate how participants who were highly dedicated to dynamic representation in multimodal, synchronous communication managed to coordinate their efforts during virtual meetings. The presented case study is explanatory (Yin, 2003). We iteratively compared the theoretical research with empirical evidence to explain how the participants managed to create and coordinate knowledge during a series of virtual meetings.

The Case Study

The investigated virtual meetings took place in a joint venture between a small Danish software company in Copenhagen (Software.DK) and a Russian R&D outsourcing provider in St. Petersburg (Software.RU). Software.DK was established in January 2006 by four Danish partners who between them had 30 years of experience in developing computer simulations and intelligent learning solutions. Previously, they developed a portfolio of advanced medical micro-simulators based on collaboration with Software.RU and other software development outsourcing companies in India. Software.RU was established in 1991 and had more than 350 Russian employees. The company had been engaged in more than 300 projects with companies from Denmark, Finland, Germany, Sweden, and the US.

Software.DK initated the project in February 2006 with the goal of developing a web-based, collaborative mindmapping tool to support software development. The joint venture was established with Software.RU in April 2006 and named the Comapping Project. The two companies had equal ownership, but made different contributions to the project. Software.RU initially assigned two developers to the project, while Software.DK provided management, architectural, and design expertise. With two developers in Software.DK initially working full-time on the project along with the two Russian developers, there was a proof of concept ready the following month.

The Comapping Project shifted its focus and hired three managers to develop a commercial strategy for the new tool. The managers were, however, not able to agree on a strategy and were therefore released from the project. After the three managers were released, the project entered a period of technically focused management aimed at finalizing a first, full version of the tool. It was at this point, in early 2007, that we initiated contact with the Comapping Project. We started to systematically observe all virtual meetings between the Danish and Russian sites in April 2007. A team consisting of the Comapping Project's CEO, a board member of Software.DK, and the Russian software development manager managed the project. Three months later, the project reached a major milestone when a Fortune 500 Company invested in the tool. As a result, customizing the tool to the new partner's requirements became the primary objective and the Comapping Project's staff was increased to eight full-time developers. Our case study ended in August 2007, when the project reached this milestone and was reorganized.

Coordination through virtual meetings relied on teleconferencing via Skype (www.skype.com) combined with real-time collaborative modeling via the mindmapping tool (www.comapping.com). Virtual meetings were held between the Software.DK board member (representing management), the joint venture CEO (representing marketing), and the Russian software development manager (representing product development). The meetings did not include video feeds of participants because their focus was entirely on real-time manipulation of the shared mindmap. The conference language was English and all virtual meetings took place in normal working hours as the time-zone difference between Copenhagen and St. Petersburg is only two hours. The virtual meeting structure was closely reflected in the mindmap tool. Figure 1 shows the mindmap at the start of a meeting and Figure 2 the revised mindmap resulting from the meeting.

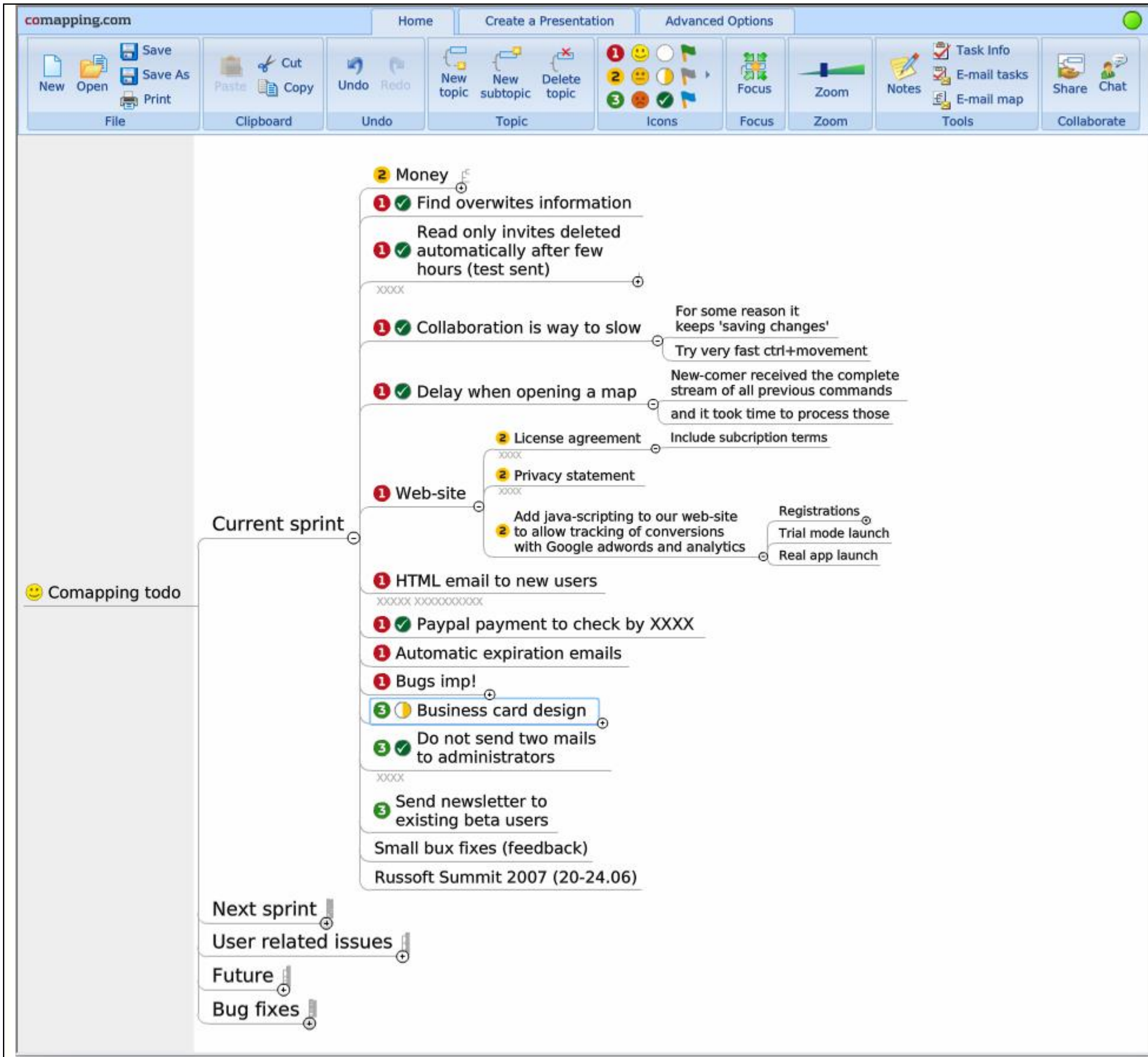


Figure 1. Screenshot of the Comapping Mindmap before the Virtual Meeting on May 21, 2007

The root “comapping todo” has two sub-nodes: “current sprint” and “next sprint”. Their sub-nodes represent assignments to individual team members or groups. Assignment priorities are usually indicated by a number and development status with a checkmark or an empty, half-, or three-quarter-full circle. These priority and status indicators are also applied to sub-nodes of the mindmap hierarchy (e.g., “Web-site” (Figure 1)). Another frequently used indicator assigns a node to a specific individual using small text boxes below the node (we replaced names with Xs). When multiple users navigate the mindmap, each individual’s cursor is visible to other users as a small box with the name of that individual. Manipulations of the mindmap (e.g., deleting, adding, or changing a node) are instantly visible to other users.

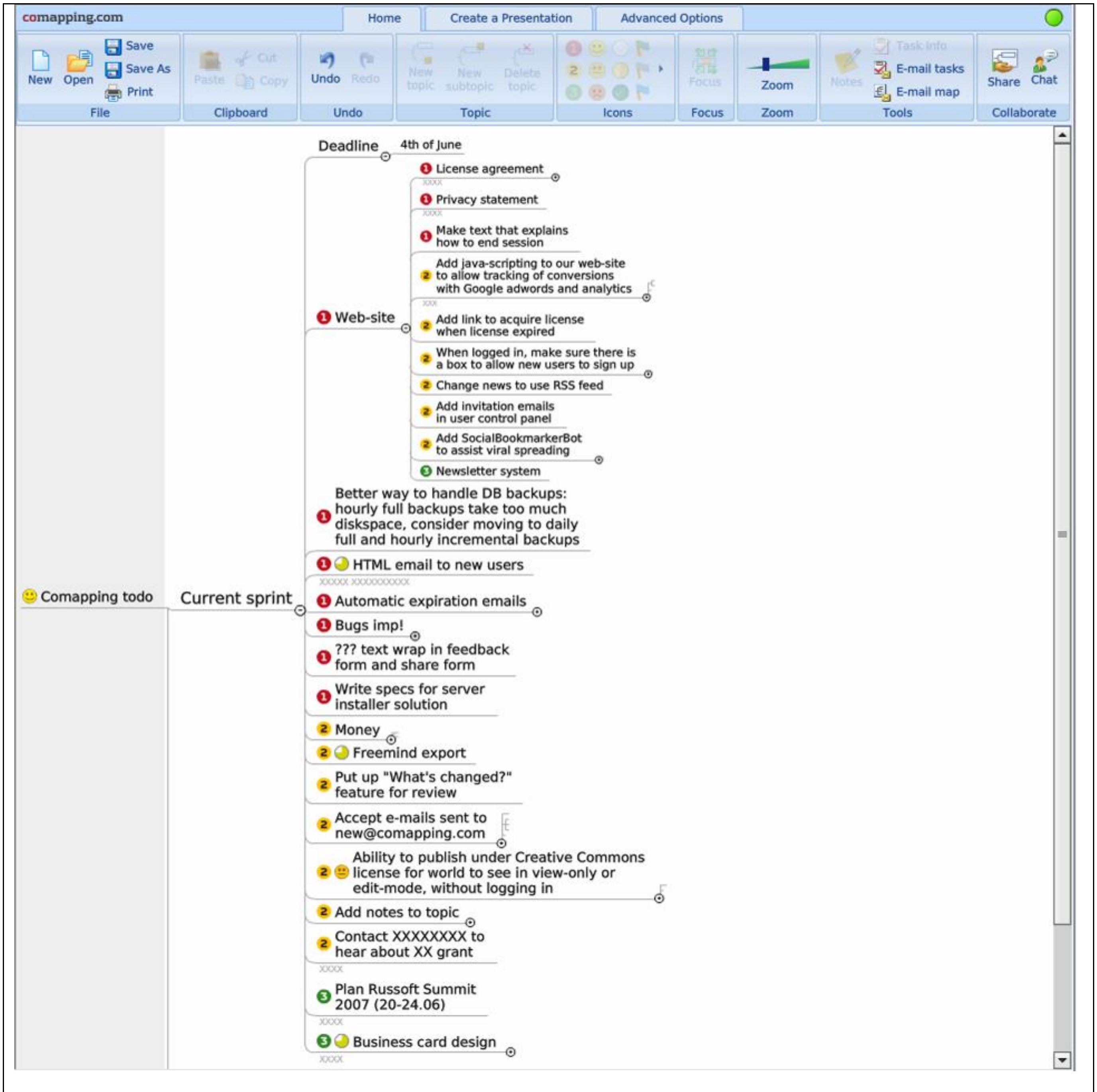


Figure 2. Screenshot of the Comapping Mindmap after the Virtual Meeting on May 21, 2007

The observed virtual meetings usually started with a walkthrough of all the sub-nodes of “current sprint”, also known as the sprint backlog, in the agile software development method Scrum (Rising & Janoff, 2000; Schwaber & Beedle, 2001). The Russian software development manager would report on the status of each node, and nodes were deleted as assignments were completed. Other assignments were elaborated with new sub-tasks or they were given alternative priority or status. New assignments might also be introduced during this initial walkthrough. Virtual meetings would then typically continue with a walkthrough of “next sprint” with sub-nodes representing assignments or ideas postponed for later. This walkthrough would lead to changing the priorities of some sub-nodes or relocating sub-nodes to “current sprint”. By the end of a virtual meeting, the participants would revisit “current sprint” and consider the feasibility of assignments and agree on a deadline for the sprint. The sub-nodes of “current sprint” would also be ordered according to priority, with the highest priorities placed highest.

We collected data about the Comapping Project from January 2007 through August 2007, including a field visit at the Danish site, recordings of the virtual meetings, and team member interviews focused on the wider context. During the virtual meetings, the first author was present offsite as a passive observer. He audio and video recorded conversations and real-time collaborative modeling in the virtual meetings. Thus, our observations were not tied to a specific participant's perspective in the virtual meetings. In total, we observed seven meetings from April 2007 to July 2007 (Table 1). The observations were initiated when the marketer was recruited to the project and ended when the Fortune 500 Company invested in the tool. Even though the mindmapping tool had not been officially released when the data collection started, all its basic functionality was readily available for the team's virtual meetings.

Table 1. Virtual Meetings in the Comapping Project

Virtual Meeting #	Date	Duration	Participants
1	April 24	32 min	Marketer, Manager, Developer
2	May 3	37 min	Marketer, Manager, Developer
3	May 16	17 min	Marketer, Manager, Developer
4	May 21	64 min	Marketer, Manager, Developer
5	June 4	32 min	Marketer, Manager, Developer
6	June 26	50 min	Marketer, Manager, Developer
7	July 2	15 min	Marketer, Manager, Developer

Before we started observing virtual meetings, we conducted semi-structured interviews to understand the organization and work-group contexts (Majchrzak, Rice, Malhotra, King, & Ba, 2000). These interviews were initiated with a face-to-face meeting with the manager of the Comapping Project followed by interviews with other project members via Skype. Towards the end of our observations, we conducted a new series of interviews with key project members and the CEO of Software.DK. In total, we conducted eleven interviews (Table 2).

Table 2. Semi-structured interviews

Site and nationality	Role	Background	Date (2007)
Denmark	**Manager** Board member of the Comapping Project and Director of Technology & Innovation at Software.DK	Co-founder of Software.DK in 2006 and earlier co-owner of a software company in which he was director of research and technology with responsibility for managing global projects and outsourcing relationships based on agile approaches. Education: computer science.	January 19 March 6 April 24 June 27
Russia	**Developer** Director of R&D for the Comapping Project	Manager of an offshore development center in the Russian outsourcing provider for several years. Education: computer science.	March 22 July 13
Russia	Software developer in the Comapping Project	Three years of experience as software developer at the Russian outsourcing provider. Education: physics and mathematics.	April 5 July 17
Denmark	**Marketer** CEO for the Comapping Project	Four years of experience as strategy consultant at major consultancy firms. Specialized in front-end optimization in marketing and sales ranging from segmentation and pricing to best practice and process optimization. Education: international management.	May 8 June 28
Denmark	Chairman of the Comapping Project, and CEO of Software.DK	Co-founder of Software.DK in 2006 and earlier co-owner of a software company in which he was global director of learning products. Education: medicine and medical education.	August 8

Analytical Framework

Coordination is the management of dependencies between activities (Malone & Crowston, 1994), and understanding these dependencies requires a focus on how coordination is communicated and enacted. The language–action perspective, also known as speech act theory, provides such a focus and has previously been used in research on groupware technologies (Ngwenyama & Lyytinen, 1997; Winograd, 1987). Austin (1962) and Searle (1969) developed speech act theory based on the observation that utterances are not necessarily statements whose truth is at stake. Performatives, such as declarations or directives, can be uttered more or less appropriately, but they are not in a simple sense true or false. Similarly, commands, questions, and apologies are not descriptions of a nonlinguistic world (Winograd, 1987). Speech act theory is based on an interactional view of communication, where intersubjective meanings are found in particular and concrete acts that are spatially, temporally, socially, and subjectively located but also repeatable and rephraseable (Grossberg, 1982).

Adopting a language–action perspective to investigate how coordination was practiced in virtual meetings, we applied Searle's (1975) typology of speech acts in cooperative work (Winograd, 1987):

- **Assertive:** Commit the speaker (in varying degrees) to something's being the case—to the truth of an expressed proposition.

- **Directive**: Attempt (in varying degrees) to get the hearer to do something. These include both questions (which can direct the hearer to make an assertive speech act in response) and commands (which direct the hearer to carry out some linguistic or nonlinguistic act).

- **Commissive**: Commit the speaker (again in varying degrees) to some future course of action.

- **Declarative**: Bring about the correspondence between the propositional content of the speech act and reality (e.g., pronouncing a couple married).

- **Expressive:** Express a psychological state about a situation (e.g., apologizing and praising).

The five speech act types can be modified by the degree of illocutionary force (Holmes, 1984; Sbisà, 2001), making a statement more or less powerful. For example, a commissive speech act may be boosted or attenuated by expressions of the strength of the speaker's intention to do something (e.g., "I guess I'll probably ring you later" rather than "I solemnly promise") (Holmes, 1984). The investigated virtual meetings were, however, not limited to verbal acts through the audio modality. Participants could also act through the visual modality enabled by information technology (Winograd, 1987). In the considered case, participants complemented teleconferencing with a dynamic representation of the project status and plans based on real-time collaborative mindmapping technology. During the observed virtual meetings, participants would collaboratively, and in real time, manipulate text and other symbols to maintain a shared mindmap of current and future project activities. This technology offered seven different types of visual communication acts during virtual meetings: four allowed participants to manipulate the mindmap through the creation, deletion, movement, or renaming of nodes, and three allowed participants to add information to nodes through task assignment, node prioritization, and status reporting. These visual communication acts, along with the verbal communication acts, constitutes the coordination activities investigated in the virtual meetings' multimodal, synchronous communication.

Coordination is most clearly noticeable when it is lacking (Malone & Crowston, 1994). We therefore investigated the extent to which problems or breakdowns caused the participants to repair the communication. Breakdowns have previously been suggested for investigating the use of information technologies in virtual teams (Thomas, Bostrom, & Gouge, 2007). A communication breakdown causes a disruption in work practices and shifts participants' attention towards an appropriate repair strategy (Bjørn & Ngwenyama, 2009; Ngwenyama, 1998). However, the temporally confined virtual meetings also involve particular communication problems that are less disruptive, but nevertheless an important part of knowledge sharing and coordination. The conversations involved in virtual meetings are an integral part of social cognition where different media may change the cost of faults in utterances and the cost of consequential repairs (Clark and Brennan 1991). Faults in terms of utterance mistakes or missayings may become escalating problems that change the cost of repair. Because problems tend to snowball, participants should want to repair them as quickly as possible and at the lowest cost by, for example, changing to a different medium (Clark & Brennan, 1991). The responsibility for conversational problems is shared among the participants and has to be managed jointly (Clark, 1994). While participants prefer self-repair or may anticipate and prevent problems, the need for repair emerges in conversations as a joint problem (Clark, 1994). In this way, communication problems are defined by repairs in a reciprocal relationship. Therefore, we investigated the interrelating of verbal and visual communication acts in virtual meetings by identifying repairs that reflect communication problems.

Repairs in virtual meetings can involve instances of failed turn-taking (Garcia & Jacobs, 1999; Sarker & Sahay, 2003, 2004), technologies becoming present-at-hand (Winograd & Flores, 1986), and speakers' lacking feedback from recipients (Walther & Bunz, 2005). We investigated the repairs of incidents that compromise or challenge knowledge coordination between virtual meeting participants on four different levels (Bjørn & Ngwenyama, 2009). Lifeworld-related repairs (i.e., those about culture, beliefs, and values) occur when taken-for-granted constitutive knowledge is challenged; organization-related repairs occur when existing organizational policies, procedures, technologies, and norms are challenged; work process-related repairs occur when the efficacy of work practices and routines is challenged; and technology mediation-related repairs occur when the practical use of communication technology is challenged (Bjørn & Ngwenyama, 2009). Hence, we analyzed communication during virtual meetings by analyzing types of repairs across modalities.

In summary, we analyzed the virtual meetings by first identifying communication repairs, verbal communication acts, and visual communication acts (Table 3). We then investigated the enacted dependencies between verbal and visual communication acts in the participants' communication repairs.

Table 3. Conceptual Framework for Analyzing Multimodal, Synchronous Communication During Virtual Meetings (Adapted from Searle (1975), Winograd (1987), Clark (1994), Bjørn and Ngwenyama (2009))

Construct	Subcategory	Description
Verbal communication act	Assertive	Commit the speaker (in varying degrees) to something's being the case—to the truth of the expressed proposition.
	Directive	Attempt (in varying degrees) to get the hearer to do something. These include both questions (which can direct the hearer to make an assertive speech act in response) and commands (which direct the hearer to carry out some linguistic or nonlinguistic act).
	Commissive	Commit the speaker (again in varying degrees) to some future course of action.
	Declarative	Bring about the correspondence between the propositional content of the speech act and reality (e.g., pronouncing a couple married).
	Expressive	Express a psychological state about a situation (e.g., apologizing and praising).
Visual communication act	Create node	Making a node in the mind map.
	Delete node	Removing a node from the mind map.
	Move node	Relocating a node with or without sub-nodes in the mind map.
	Rename node	Changing the text in a node in the mind map.
	Prioritize node	Creating or changing a numeral attached to a node in the mind map.
	Assign task	Creating or changing a textual attachment with one or more names to a node in the mind map.
	Report status	Creating or changing a symbol attached to a node in the mind map that is either a checkmark or an empty, half- or three-quarter-filled circle.
Communication repair	Lifeworld	Taken-for-granted constitutive knowledge.
	Organization	Established organizational policies, procedures, technologies, and norms.
	Work process	Efficacy of teamwork practices and routines.
	Technology mediation	Practical use of technology.

Data Analysis

We coded the seven virtual meetings based on the analytical framework in Table 3. We identified verbal communication acts in the teleconferencing data and visual communication acts in the collaborative mindmapping data. We identified communication repairs based on both the verbal and visual communication. These repairs convey the participant's ability to manage dependencies between activities during the virtual meetings and they show the particular role of sharing a dynamic representation of co-created knowledge during the communication. Finally, we analyzed the eleven semi-structured interviews to understand the context, antecedent conditions, and outcomes of the observed virtual meetings. We used Atlas.ti (Hwang, 2008; Muhr, 2008) to directly code recordings from the virtual meeting.

The first author initially coded verbal and visual communication acts in the longest virtual meeting. The second author critiqued the coding, which lead to minor improvements of the coding scheme. The scheme was then shared with a research assistant, who, along with the first author, recoded the longest virtual meeting. In case of disagreements, the two coders discussed the coding options until they agreed. There were no disputes in 90 percent of instances. The second author then reviewed the coding of the longest virtual meeting by evaluating five randomly chosen instances of each verbal communication subcategory. Only one verbal communication act of the declaration subcategory led to disagreement, indicating 96 percent (24/25) agreement. We then coded all virtual meetings according to the coding scheme by the first author and the research assistant.

We initiated the coding of communication repairs in virtual meetings by introducing the coding scheme in Table 3 to the research assistant. The first author and the assistant then coded three meetings. In cases of disagreement, they discussed the options until they agreed. In this first step, 45 percent of the coded instances initiated no dispute between the two coders. The second author reviewed the coding and that led to a more inclusive interpretation of communication repairs. As a second step, the first author and the research assistant coded two additional meetings, where 65 percent of the instances caused no dispute between the coders. Once again, the second author reviewed the coding, which led to two re-categorizations and one deletion out of 22 identified communication repairs (86 percent agreement rate between the two coders and the second author). The review also led to further clarification of the coding scheme. In a final step, the first author and assistant coded all virtual meetings from scratch. In this process, 90 percent of the coded instances initiated no dispute between the two coders. In cases of disagreement, we discussed the options we agreed. Finally, we identified the participants primarily involved in each communication repair.

We systematically triangulated the analyses of audio and video recordings of the seven meetings with the interview data presented in Table 2. We recorded and revisited the interviews multiple times throughout the analyses in order to establish antecedent conditions and outcomes, to address ambiguities in our analyses, and to compare our findings with the participants' perceptions. In this way, we related our analyses of the collaborative technology during the Comapping meetings to the organizational and work-group contexts (Majchrzak et al., 2000).

IV. RESULTS

Initially, we examined data based on the framework in Table 3. Table 4 and 5 summarize the verbal and visual communication acts during the Comapping Project's meetings and Table 6 summarizes the communication repairs and which participants were primarily involved.

Table 4. Distribution of Communication Acts in the Verbal Modality

	Manager	Developer	Marketer	Total
Assertive	72	114	39	225
Commissive	27	54	58	139
Declarative	7	2	5	14
Directive	72	21	74	167
Expressive	39	29	26	94
Total	217	220	202	639

Overall, we identified 639 verbal communication acts, which corresponds to 2.6 (639/247) per minute. Verbal communication acts were equally distributed across participants, while the distribution of each type differed considerably (Table 4). Assertive acts were most frequently performed by the developer and least by the marketer; commissive acts were least frequently performed by the manager; declarative acts were relatively rare; directive acts were less frequently performed by the developer; and expressive acts were almost evenly distributed.

Table 5. Distribution of communication acts in the visual modality

	Manager	Developer	Marketer	Total
Assign task	7	1	3	11
Create node	39	5	11	55
Delete node	20	10	8	38
Move node	30	1	1	32
Prioritize node	22	4	3	29
Rename node	12	0	3	15
Report status	9	8	6	23
Total	139	29	35	203

We identified 203 visual communication acts, which corresponds to 0.8 (203/247) per minute. Visual communication acts were unequally distributed across participants (Table 5): the manager was responsible for 69 percent (139/203), the marketer for 17 percent (35/203), and the developer for 14 percent (29/203). The most evenly distributed type was report status, while the most unevenly distributed was move node.

Table 6. Distribution of Repairs

Repairs		Lifeworld	Organization	Work process	Technology mediation	Total
		11	7	33	10	61
Primarily involved participants	Manager	8	5	24	8	45
	Developer	8	5	21	5	39
	Marketer	7	5	22	4	38

We identified a total of 61 repairs, which corresponds to 0.25 (61/247) per minute. The most frequently occurring type was related to work process and accounted for 54 percent of the total (33/61) (Table 6). The remaining repairs were equally distributed between lifeworld, organization, and technology mediation incidents. The participants had an equal primary involvement in the repairs with the exception of those related to technology mediation, where the manager was primarily involved more often.

As a next step, we investigated the interrelation of verbal and visual communication acts in the repairs. For each type of communication repair, we conducted detailed analyses of exemplar repairs and analyzed related participant perceptions based on interviews with members of the Comapping Project.

Technology mediation

Technology mediation-related repairs occurred when the practical use of teleconferencing and collaborative mindmapping was challenged. This type of repair was rare (10/61 in Table 6) and mostly involved technology issues. Table 7 overviews all technology mediation incidents. The technical difficulties repaired were poor sound quality, network connection failure, error in the mindmap tool, and erroneous participation representation in the mindmap; the other repairs involved attention to e-mail errors, how to operate the mindmap tool where these technologies became present-at-hand (Winograd & Flores, 1986), and problems related to turn-taking.

All three actors in the virtual meetings had previous experience working in virtual teams. In an interview, the marketer argued for the adopted approach to collaborative mindmapping by critiquing communication technology choices such as teleconferencing and email in his past virtual team experiences. Hence, the actors' past experiences of working in virtual teams influenced their technological capabilities during the considered multimodal communication in the Comapping Project.

Table 7. Technology Mediation Incidents

Incident	Occurrences
Poor sound quality	3
Network connection failure	2
Error in the mindmap tool: slow update of manipulation in the mindmap	1
Erroneous participation representation in the mindmap	1
Attention to e-mail errors	1
Attention to how to operate the mindmap tool	1
Failed turn-taking among participants	1

While turn-taking is considered a challenging issue in mediated communication (Garcia & Jacobs, 1999; Sarker & Sahay, 2003), there was only a single significant turn-taking repair during the Comapping Project's meetings. This incident involved the manager and marketer (Figure 3), and it included one visual communication act, assign task (line 5), and three verbal communication acts, two directive (lines 2 and 5), and one commissive (line 3).

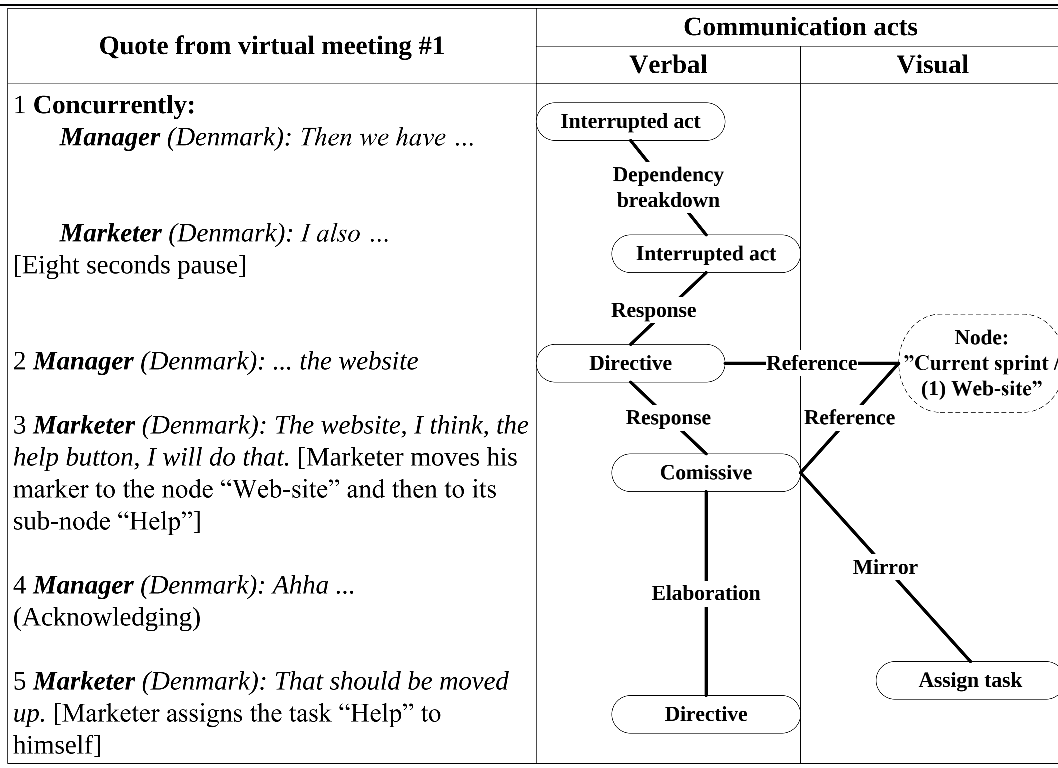


Figure 3. Extract from Virtual Meeting #1 and Map of Communication Acts

In line 1, the manager and marketer articulate simultaneously, causing a period of silence. In line 2, the manager repairs with a directive act, expressed through the shared reference point, “Web site”, in the mindmap. By referring to a specific node, the manager brings immediate attention to what he intends to communicate and reduces the likelihood of misunderstandings. The marketer then repeats the manager’s statement in line 3 and places his marker on the “Web site” node. The marketer continues with a commissive act in line 3 supplemented by the visual communication act in line 5, where he elaborates with a directive verbal communication act. Figure 3 illustrates how the manager and marketer quickly repair the turn-taking incident: they interrelate verbal and visual communication acts by mirroring and referencing across modalities. This practice occurred frequently during the Comapping Project’s meetings: 42% (86/203) of the visual communication acts were combined with verbal communication acts.

While failed turn-taking (as in Figure 3) can be problematic in virtual meetings, the analyzed breakdown had a limited adverse effect on the communication between the manager and marketer. Moreover, in the repair, the two participants exploited both communication modalities. The participants subordinated their articulations and manipulations to the dynamic representation readily available in the mindmap. Hence, the extract in Figure 3 shows how the participants interrelated the verbal and visual modalities in the repair. In total, we identified only one turn-taking repair in 203 manipulations and 639 articulations during seven virtual meetings and four hours of activity. This low number indicates high coordination performance in the Comapping Project’s meetings because failed turn-taking is a common challenge in mediated communication (Garcia & Jacobs, 1999; Sarker & Sahay, 2003).

Work Process

Work process-related repairs occurred when the efficacy of coordination practices and routines during the Comapping Project’s meetings were challenged. This type of repair, constituting 54 percent (33/61) of all repairs during the meetings (Table 6), was the most frequent. Table 8 overviews the individual incidents. The most frequent incidents were “participants request repeat of articulation” and “uncertainty concerning how to use the mindmap tool”. These two type of incidents accounted for 38 percent (23/61) of all observed communication repairs.

The Comapping Project did not only coordinate knowledge through the virtual meetings. In an interview, the manager argued that email notifications of code contributions sent to all project members served as a simple but important knowledge coordination mechanism. The email notifications were systematically reviewed by both the developer and the manager, which enabled them to gain detailed knowledge of the progress and quality of project members’ contributions. The manager also noted that, while everyone can make mistakes, a systematic review process afforded early discovery of most errors, avoiding later cost escalation. A similar review process was conducted when code was transferred from the test server to the production server. The manager also regularly communicated directly with the developers in Russia without involving the managing developer, and thereby gained further detailed knowledge of the project. In his account of these activities, the manager emphasized the importance of his continued high attention to quality in even the smallest detail, which eventually was imitated by the other actors in the Comapping Project.

Table 8. Work Process Incidents

Incident	Occurrences
Participants request repeat of articulation	12
Uncertainty concerning how to use the mindmap tool	11
Participants show misrepresentation of information articulated by another participant	6
Talking on the phone during the virtual meeting	2
Failed coordination of mindmap manipulations	1
Misrepresentation of information in the mindmap	1

The most frequent incident was “participants request repeat of articulation”, which constitutes 20 percent (12/61) of all work process repairs. This incident was a very common conversational repair and it is interesting to observe how the participants responded during Comapping Project’s meetings. Figure 4 presents one typical repair involving the manager and the developer. The extract includes two visual communication acts, the create node (line 3) and prioritize node (line 6), and six verbal communications acts, three directives (lines 1, 2, and 3), one assertive (line 4), one commissive (line 5), and one declarative (line 6).

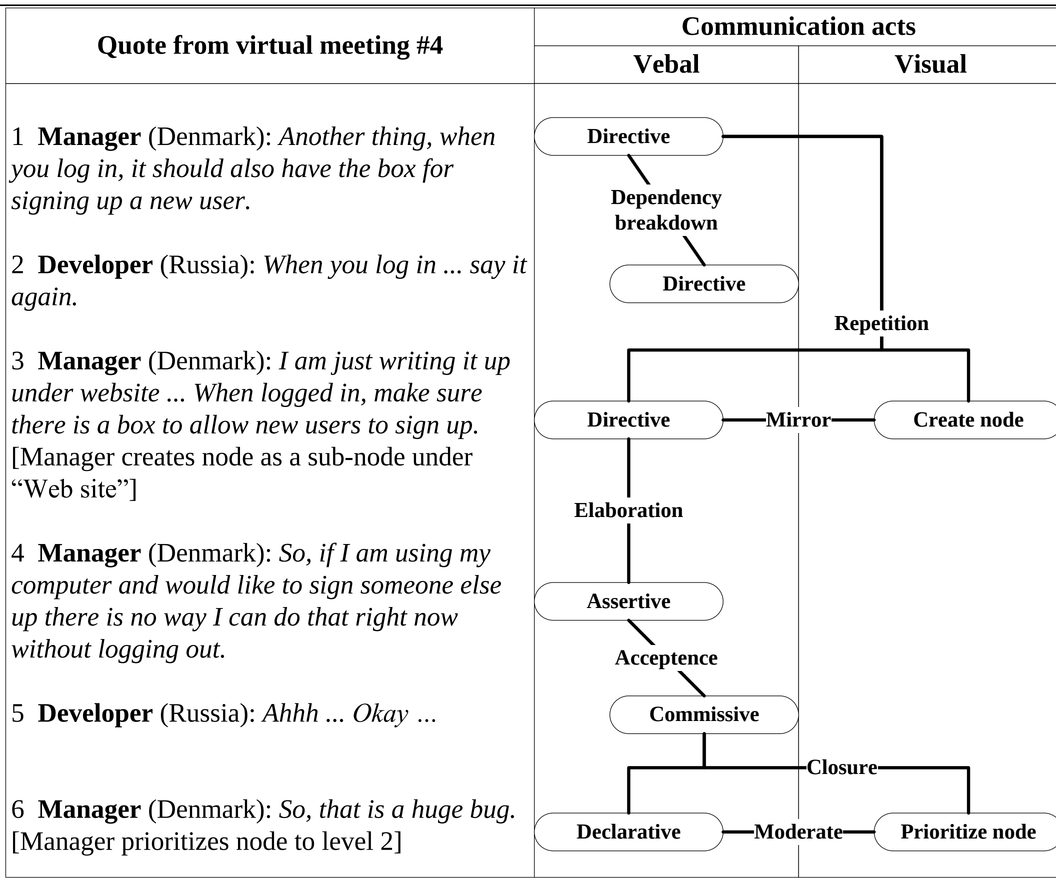


Figure 4. Extract from Virtual Meeting #4 and Map of Communication Acts

The manager articulates a directive in line 1. However, the developer appears inattentive and articulates in line 2 a directive, requesting the manager to repeat his verbal communication act. In response, the manager repeats his initial directive in line 3 while also creating a node mirroring this directive. Then, the manager emphasizes the directive with an assertive communication act in line 4. The developer acknowledges with a commissive act in line 5 and the manager declares it is a huge bug in line 6. The extract in Figure 4 illustrates how the manager engages in the repair by mirroring his verbal communication acts in the dynamic representation. The combination of verbal and visual communication is similar to the extract in Figure 3. Line 6 in Figure 4 illustrates an interesting inconsistency between the manager's verbal and visual communication acts. While boosting the illocutionary force of the verbal communication act (Holmes, 1984; Sbisà, 2001) by stating it is "a *huge* bug", the manager sets the node priority to level 2. So, in this case, the declarative verbal communication act was modified by a visual communication act. The combination of modalities in this case illustrates a moderating relationship in which a communication act in one modality moderates the force of an act in the other modality.

The developer's request for repeating an articulation was attended to by the manager because he immediately exploits both communication modalities to repeat his initial verbal communication act in the repair. Interestingly, this shows how a participant during the Comapping Project's meeting exploited the dynamic representation to mirror and moderate verbal communication acts when engaging in a repair.

Organization

Organization-related repairs occurred when existing organizational policies, procedures, technologies, and norms for coordination during the Comapping Project's meetings were challenged. This type of repair, constituting only 11 percent (7/61) of the incidents (Table 6), was the least frequent. Table 9 overviews all organization repairs.

The Comapping Project's participants experienced difficulties in prioritizing product features. In an interview, the manager pointed out that task prioritization had been a significant challenge between him and the developer during the start of the project. Back then, they maintained a list of prioritized tasks. However, they ended up with a large number of tasks with first priority, and it was difficult for the developer to prioritize between them. Subsequently, the project adopted time boxing in the form of sprints and started to use the mindmapping tool. Project tasks were in this way structured and prioritized in a straightforward fashion and explicitly represented in the mindmap, which allowed actors to coordinate knowledge more easily and as needed. The chairman of the Comapping Project described it as having two timelines, one for product development and one for marketing, and the mindmap was predominantly related to product development with little consideration of marketing. The recent joining of the marketer involved knowledge coordination difficulties. However, the Russian developer who did not participate in the meetings stated the marketer had a revitalizing effect on the Comapping Project. The marketer's pressure to move forward, even beyond team capabilities, gave this developer a more positive perception of the project.

Table 9. Organization Incidents

Incident	Occurrences
Unclear procedures for business strategies	1
Unclear responsibilities for documentation of agreements	1
Norms of efficiency in the project are challenged	1
Inability to recall previous undocumented agreements	1
Unclear responsibilities for paying fees to external party	1
Participants focus on what should be discussed in the technical focused virtual meetings	1
Undecided procedures for server-upgrading	1

One organization repair involving the marketer was "unclear procedures for business strategies". This particular incident unfolded as a debate over six minutes, making it the most time-consuming repair during the observed meetings. The incident illustrates the difficulties in knowledge sharing and coordination between development and marketing (Griffin & Hauser, 1996). In the following paragraphs, we analyze the initial part of this incident involving the marketer, manager, and developer (Figure 5). The extract includes six verbal communication acts, three assertive (lines 1, 3, and 10), two directive (lines 7 and 8), and one commissive (line 5). The assertive and commissive communication acts in lines 3 and 5 are restatements by the marketer from a different context before the virtual meeting:

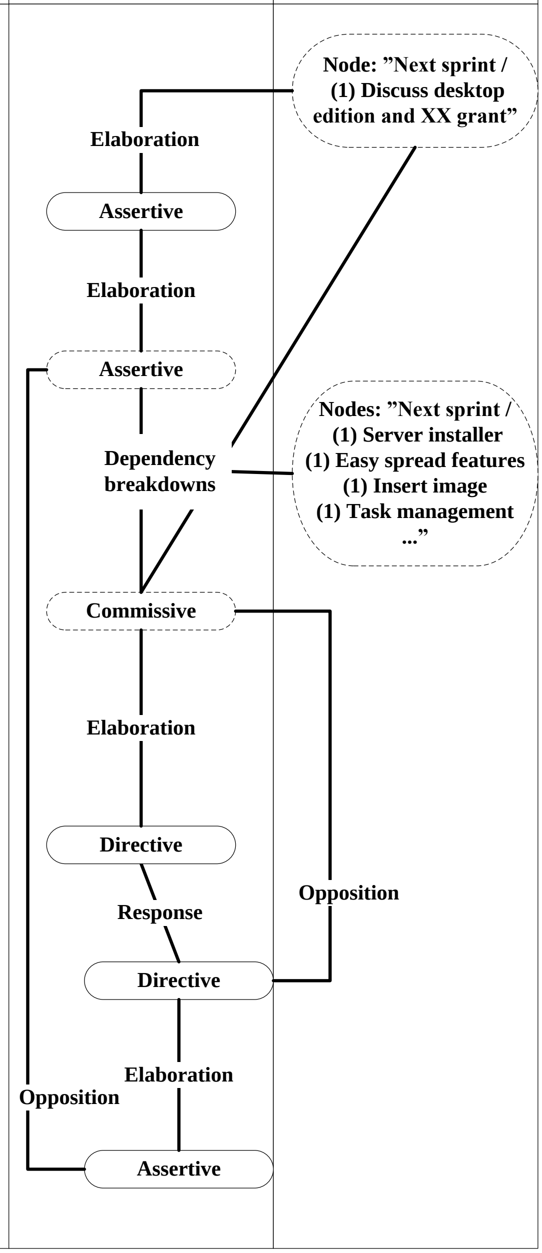
Quote from virtual meeting #4	Communication acts: Verbal / Visual
[All place markers on the node ”Discuss desktop edition and XX grant” with priority 1 under ”Next sprint”] 1 **Marketer** (Denmark): *“Developer,” we talked about the desktop application.* 2 **Developer** (Russia): *Yeah.* 3 **Marketer** (Denmark): *And also “Manager,” we were thinking that the desktop application should be launched no later than two months.* 4 **Manager** (Denmark): *No later or not earlier?* 5 **Marketer** (Denmark): *Well, I have told people, well only a few. I was thinking we should launch it between one or two months from today’s date.* 6 **Manager** (Denmark): *Well, hehe ... (Short laugh).* 7 **Marketer** (Denmark): *Is that possible? I’m just thinking how should we integrate this into the current sprint?* 8 **Manager** (Denmark): *I think that you need to stop telling people when things will come, before we have decided.* 9 **Developer** (Russia): *Hehe ... (Laughing)* 10 **Manager** (Denmark): *We don’t know the impact of the desktop application. We don’t know how long it will take yet.*	

Figure 5. Extract from Virtual Meeting #4 and Map of Communication Acts

In this part of the incident, the marketer asserts in line 1 that a previous discussion with the developer regarding a desktop application version of the Comapping tool has taken place. He also refers to an assertion concerning a deadline in line 3, made before this virtual meeting, and elaborates having shared this information with other people in line 5. The marketer thereby refers to a commissive communication act he made outside the virtual meeting context. Almost concurrently with the manager’s short laugh in line 6, the marketer in line 7 elaborates with a directive by asking whether this goal is possible and how they can integrate it into the current sprint. In response, the manager articulates a directive in line 8, opposing the marketer sharing such information to people without coordination in the virtual meetings. The developer briefly laughs, suggesting disagreement with the marketer; this disagreement becomes more pronounced later during the incident. The manager then elaborates his directive with the assertive communication act in line 10. As a consequence, the manager agrees by the end of the incident that they should not prioritize the desktop application.

The repair presented in Figure 5 differs from the repairs presented in Figures 3 and 4 by involving multiple dependencies. First, the marketer did not heed the division of tasks into current sprint (planned tasks) and next sprint (suggested tasks) in the mindmap by talking about the “desktop edition” task in terms of a deadline, which, according to their procedure, is only done for tasks in the current sprint. Thus, he failed to consider the prioritization of the “desktop edition” task in relation to the other tasks in the next sprint category. Furthermore, the dependency between what the marketers had discussed with the developer (line 3) and the following commissive made to people externally (line 5) shows lacking interrelation with the other participants in the virtual meeting. The marketer’s commissive communication act to external parties never became an interrelated contribution as part of an explicit representation of the Comapping Project. While the marketer’s referral to a discussion with the developer in line 1 suggests interrelatedness between the two, his attempt to include the desktop application in the current sprint in line 7 was unsuccessful. This lack of interrelatedness on the desktop edition task was explicitly pointed out by the manager in line 8, and, later in the incident, the developer also challenged the marketer’s representation in line 3. Hence, the marketer’s contribution related to the desktop application was not interrelated to the dynamic representation of the project’s plans, despite his attempt to make it so. Thus, this particular issue occurred before the virtual meeting, but became apparent through the marketer’s account of former acts in conjunction with a task in the mindmap. This interrelation allowed for repair in the virtual meeting because the marketer attempted to interrelate his contribution, even though the repair was more time consuming with multiple dependencies.

Lifeworld

Lifeworld-related repairs occurred when taken-for-granted constitutive knowledge underpinning the coordination during the Comapping Project’s meetings was challenged. This type of repair constituted 18 percent (11/61) of the incidents and was the only type evenly triggered by the marketer, manager, and developer (Table 6). Lifeworld repairs were predominantly related to a need for conveying taken-for-granted professional or cultural knowledge. Table 10 provides an overview of all observed lifeworld repair incidents.

The Comapping Project involved actors with different lifeworlds in their respective settings (the mid-sized Russian outsourcing provider and the small Danish software company). According to the project’s chairman and to its manager, a high level of trust had been established through past collaboration before the joint venture and Software.DK was established. However, the marketer did not share this history with the other participants because he was recently affiliated with the Comapping Project. Hence, he had a fundamentally different professional background as expressed in one incident where he stated he didn’t understand the issue being discussed and didn’t expect he had to, with which both the manager and the developer agreed.

Table 10. Lifeworld Repairs

Incident	Occurrences
A need for conveying fundamental professional knowledge	4
A need for conveying fundamental cultural knowledge	4
Ambiguous language use	1
Uncertainty regarding name articulation	1
Unawareness of the physical location of a new participant	1

One repair related to “a need for conveying fundamental cultural knowledge” involved an effort to explain a technical requirement based on a particular use case. However, differences in contextual knowledge about the use case triggered a dispute between the developer and the manager. Figure 6 illustrates part of this incident; the extract includes six assertive communication acts (lines 1, 2, 3, 4, 5, and 8) and two directive communication acts (lines 6 and 7).

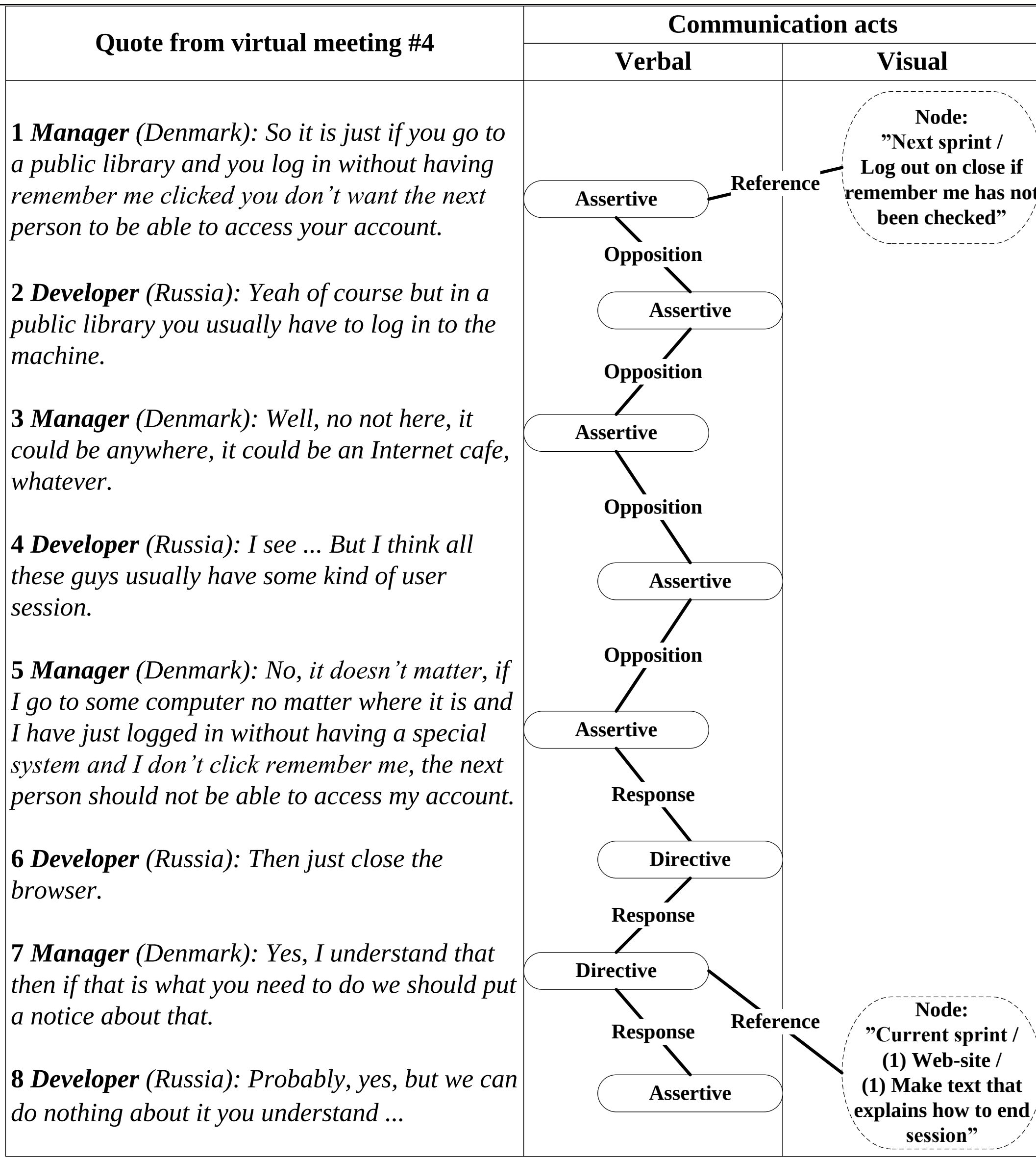


Figure 6. Extract from Virtual Meeting #4 and Map of Communication Acts

The part of the incident preceding the extract in Figure 6 concerns a sub-node of the next sprint called “Log out on close if remember me has not been checked”. The developer follows the established routine by accounting for the status and challenges related to the task represented by the node. However, the manager disputes the developer’s account of the task’s key challenge. In an attempt to communicate his perspective more clearly, the manager asserts an exemplary use situation at a public library in line 1. However, the developer opposes the circumstances of the exemplary use situation with an assertion in line 2. In opposition, the manager asserts the challenge of circumstances isn’t valid in his lifeworld and instead refers to another exemplary use situation in line 3. Again, opposed by the developer’s assertion in line 4, the manager further opposes with an assertion in line 5, and the developer responds with a directive in line 6. The manager responds with the directive that it should be communicated in the product in line 7, which references to a node representation of such a task later created in the mindmap. The developer then makes an assertive communication act in line 8 elaborating the reasons why no technical solutions are available to address the concerns raised by the manager.

In Figure 6, the participants express different perceptions of the exemplary use situation grounded in their Danish and Russian lifeworlds. While the exemplary use situation seeks to ease difficulties in communicating requirements, a repair emerges because of differences in the team members’ lifeworlds. However, the manager quickly contributes to the repair by shifting to a different reference point. He thereby limits the need for interrelating the participants’ respective Russian and Danish contexts.

V. DISCUSSION

Drawing on the theories of speech acts (Winograd, 1987) and communication repairs (Bjørn & Ngwenyama, 2009; Clark, 1994), we investigated the research question: How does dynamic representation of co-created knowledge in multimodal communication affect coordination during virtual meetings? Based on our analyses of multimodal communication during the Comapping Project's meetings, we first discuss key empirical evidence of how dynamic representation facilitated repairs. Subsequently, we draw on the empirical evidence to offer theoretical propositions that explain how sharing dynamic representations of co-created knowledge in multimodal communication can enable repairs in virtual meetings. Finally, we argue that the presented framework for analyzing communication repairs provides researchers with a novel and practical approach to investigate complex data from virtual meetings that involve multimodal, synchronous communication.

Dynamic Representations during Virtual Meetings

During the Comapping Project's virtual meetings, the participants negotiated the specification of tasks, their priority, and the time box in which they should be addressed. Teleconferencing and collaborative mindmapping mediated these interactions. Teleconferencing offered easy and frequent verbal communication during the seven virtual meetings combined with visual communication based on dynamic representation of project status and plans in the mindmapping tool (Figure 4). Communication with one modality often relied heavily on the other modality (Figures 3 and 4), enhancing turn-taking capabilities (Garcia & Jacobs, 1999; Sarker & Sahay, 2003) and moderating communication acts (Holmes, 1984; Sbisà, 2001).

The verbal modality offered easy and frequent procurement of contributions during the seven virtual meetings. Moreover, the communication of a contribution was typically reinforced by a subsequent visual communication act in the mindmap. As the manager was by far the most dominant manipulator of the mindmap, he had a powerful role in continuously shaping the participants' shared representation of the project during the meetings (Table 5). Contributions were at times initiated as visual communication acts; however, not without subsequent verbal acts.

The participants' interdependent actions in the virtual meetings were continuously shaped and maintained through a combination of verbal acts through teleconferencing and visual acts manipulating the shared mindmap. Each participant verbally articulated personal representations of their endeavors, which were notably influenced by their respective role (Figure 5) (Griffin & Hauser, 1996). As key representations were shared through visual communication acts in the mindmap, it became transparent how individual participants' representations were related and whether what was articulated was consistent with what had previously been agreed on. In this way, the dynamic representation helped the participants immediately identify differences and inconsistencies in representations and supported subsequent resolution verbally.

The evolving system of interdependent actions during the virtual meetings involved effective communication repairs. The participants furthermore reduced the need to integrate their respective Russian and Danish contexts (Figure 6). The dynamic representation provided the participants with a comprehensive overview through which they continuously interrelated their actions. The ready-at-hand representation included goals, tasks, commitments, and priorities and was updated in real time during meetings (Figure 3). This up-to-date and comprehensive representation of core dependencies in the virtual meetings helped the three participants continuously keep track of essential project issues and commitments.

The analyses of verbal communication acts, visual communication acts, and communication repairs during the virtual meetings demonstrate how the dynamic representation of the project status and plans facilitated effective interrelation of actions between the marketer, manager, and developer. Most importantly, there was a low frequency of repairs; these repairs never severely disrupted the coordination efforts as the participants immediately managed to return to the coordination issues at hand; and, when repairs showed problems (Figure 4), other participants effectively employed the dynamic representation in the repair.

Enabling Repairs with Dynamic Representations

To support further the investigation of how dynamic representations of co-created knowledge in multimodal communication practices affect repairs, we present three theoretical propositions based on the findings from the Comapping Project's meetings and extant literature. Each proposition captures multimodal communication practices with dynamic representation that enable technology mediation-, work processes-, organization-, and lifeworld-related repairs (Bjørn & Ngwenyama, 2009; Clark, 1994).

Technology mediation-related repairs occurred when the use of technology was challenged during the meetings. One of these repairs was based on failed turn-taking between the manager and marketer. The repair was effectively and efficiently supported by the manager's combination of verbal and visual communication (Figure 3). The practice of interrelating verbal and visual communication acts occurred frequently: 42 percent (86/203) of all visual communication was combined with verbal communication. Failed turn-taking is a common challenge in virtual teams' mediated communication (Garcia & Jacobs, 1999; Sarker & Sahay, 2003) as "norms of turn-taking in conversation and presence that are usually well-established among individuals in a face-to-face context are not applicable when interactions, synchronous or asynchronous, occur in a virtual medium" (Sarker & Sahay, 2004). However, in the Comapping Project, only a single significant turn-taking repair was identified over the course of 203 visual and 639 verbal communication acts during seven virtual meetings and four hours of activity. This low number indicates the communication practice of combining verbal and visual communication helps prevent and overcome failed turn-taking. Another similar, but more obvious technology mediation repair is when one modality is used as a substitute for another temporarily unavailable modality, as in the observed incidents of poor sound quality and errors in the mindmap tool (Table 7).

The practice of interrelating communication acts across verbal and visual modalities also helped work process repairs in which the efficacy of virtual meeting practices and routines were challenged. In one of these repairs, a participant was inattentive during a verbal communication act, prompting the other participant to mirror his previous verbal communication acts in the visual modality (Figure 4). This kind of work process repair was occurring relatively frequent (Table 8), likely because of lack of cues such as body language in mediated communication compared to face-to-face communication (Walther & Bunz, 2005). Although the practice of overt acknowledgement of receipt (Walther & Bunz, 2005) was not systematically adopted in the virtual meetings, the participants were able to effectively repair moments of inattention by mirroring past communication acts in another modality (Figure 4). In the Comapping Project's meetings, the responding participant reconstructed his contribution multiple times in a repair. In doing so, he relied on the dynamic representation of the project that was constructed and shared through the combined use of teleconferencing and collaborative mindmapping. These findings motivate the following proposition:

> **Proposition 1:** *The practice of using dynamic representation of co-created knowledge to interrelate communication acts across verbal and visual modalities during virtual meetings enables technology mediation and work process-related repairs.*

Organization-related repairs occurred when established policies, procedures, technologies, and/or norms were challenged during the Comapping Project's meetings. One of these repairs illustrates the difficulties in coordination between different organizational roles (Griffin & Hauser, 1996; Robey et al., 2000). The repair was related to the coordination of commissive acts to external parties and the related prioritization of tasks in the project (Figure 5). However, because key communication acts were conveyed through manipulations in the mindmap, it became transparent how individual participants' coordination activities were related and whether what was communicated was consistent with what had previously been agreed on. In this way, collaborative mindmapping helped the participants immediately identify knowledge differences and inconsistencies and supported subsequent resolution through teleconferencing. Organization repairs were relatively rare in the meetings and they were non-repetitive (Table 6). These findings show how the participants engaged in organization related repairs to overcome challenges related to task coupling (Ramesh & Dennis, 2002; Sakthivel, 2005; Sutanto et al., 2011), task awareness (Espinosa et al., 2007), and inter-functional conflict resolution (Robey et al., 2000).

During the early stages of the Comapping Project, task management caused considerable organizational difficulties in virtual meetings. According to the manager, the team initially had a large number of tasks with first priority, which made it difficult for the developer to prioritize between them. This experience motivated the structuring of the project into sprints (Rising & Janoff, 2000), which allowed them to time box (Jalote, Palit, Kurien, & Peethamber, 2004) specific tasks. During the observed meetings, the participants negotiated the specification of tasks, their priority, and the time box in which they should be addressed. In this coordination, the mindmapping tool helped them continuously negotiate issues and maintain a shared understanding through a simple and ready-at-hand representation of key commitments. In this way, the systematic separation, but still coherent representation, of topics enabled communication repairs by helping the three participants contribute and subordinate to the project based on a shared and continuously updated representation of key commitments.

Time boxing limited the participants' commitment to concurrent tasks and imposed additional structure on their meetings, which reduced the likelihood of information overload. Information overload is considered a key challenge in mediated communication (Jones, Ravid, & Rafaeli, 2004). In these situations, participants have more information available than they can assimilate (Edmunds & Morris, 2000) and this leads to loss of perspective and greater tolerance of error (Eppler & Mengis, 2004). While such effects could adversely affect the participants' ability to interrelate actions, they exploited a coherent and shared representation that helped them assign and coordinate work dynamically. These findings motivate the following proposition:

> **Proposition 2:** *The practice of using dynamic representations of co-created knowledge during virtual meetings to keep track of task distribution based on verbal negotiation of options and visual update of commitments enables organization-related repairs.*

Lifeworld-related repairs occurred when taken-for-granted constitutive knowledge was challenged. Interestingly, these repairs were relatively rare (Table 6), and they mostly related to differences in cultural and professional knowledge across sites (Table 10). In the lifeworld repair in Figure 6, the participants identified differences in cultural knowledge, but immediately move beyond these differences by agreeing on general product requirements. In a different repair, the participants explicitly agreed that professional knowledge underlying a specific action did not need to be shared. Research shows serious difficulties related to knowledge sharing across sites in distributed organizations (Cramton, 2001; Majchrzak et al., 2005; Sole & Edmondson, 2002), coined as the mutual knowledge (Cramton, 2001) or the situated knowledge problem (Sole & Edmondson, 2002). In response, it has been suggested to temporarily physically relocate participants (Sole & Edmondson, 2002) to support the communication of differences in context by information technology (Majchrzak et al., 2005) and to hone the skill of grasping local realities (Cramton, 2001). Our findings question such a strong emphasis on explicitly sharing cultural and professional knowledge across sites as a substitute for everyday sharing of contextual knowledge in collocated settings.

Inadequate individual comprehension can be compensated for through social means (Weick & Roberts, 1993). In fact, socio-cognitive theory suggests high-performing teams can be so complex that it is impossible for any single team member to hold all the knowledge required for success (Cannon-Bowers & Salas, 2001). In such cases, individuals need to specialize, and success will therefore depend on the ability to effectively coordinate the diverse knowledge of several individuals. Our findings suggest the Comapping Project succeeded to coordinate diverse knowledge during the virtual meetings by dynamically offering reference points in the mindmap rather than by explicitly sharing cultural and professional knowledge across sites. These findings motivate the following proposition:

> **Proposition 3:** *Dynamic representation of task-related reference points during virtual meetings reduces the need for sharing professional and cultural knowledge and enables lifeworld-related repairs.*

Investigating Dynamic Representation in Virtual Meetings

While the use of multimodal, synchronous communication allows participants to combine different forms of interaction during virtual meetings, it also leads to unusually complex sets of data. While a number of approaches are available for investigating multimodal, synchronous communication in teams (Avouris et al., 2003; Baker et al., 1999; Dillenbourg & Traum, 2006; Jermann, 2002; Soller & Lesgold, 2003; Suthers et al., 2001; Çakir et al., 2009), existing approaches have been developed to investigate distributed collaboration to solve well-defined problems (e.g., involving middle-school math students); they do not provide techniques for investigating audio modality as an integral part of virtual meetings, and they are either based on quantitative or qualitative analysis. To overcome these methodological limitations and to enable in-depth studies of how dynamic representation practices unfold over time and shape knowledge sharing and coordination in virtual meetings, we drew on specific constructs and integrated these into a coherent analytical framework.

The presented framework mainly relies on the conversation analytic perspectives of language action and repairs. To investigate dynamic representation in the Comapping Project's meetings, we quantitatively identified how many repairs occurred and qualitatively interpreted them. These analyses drew on virtual team research (Bjørn & Ngwenyama, 2009) to distinguish between lifeworld, organization, work process, and technology mediation communication repairs (Table 3). This approach is based on the observation that coordination is most clearly noticeable when it is lacking (Malone & Crowston, 1994). Further, to conceptualize the activities during the Comapping Project's meetings we drew on speech act theory (Austin, 1962; Searle, 1969; Winograd, 1987) to distinguish between assertive, directive, commissive, declarative, and expressive verbal communication acts. Similarly, we identified assign task, create node, delete node, move node, rename node, prioritize node, and report status as distinct visual communication acts related to dynamic representation of co-created knowledge based on collaborative mindmapping. Hence, although different contexts and forms of mediation might suggest other conceptualizations of communication repairs, verbal communication acts, and visual communication acts, we suggest the following proposition:

> **Proposition 4**: *Communication repairs, verbal communication acts, and visual communications acts offer a comprehensive and practical framework for analyzing how dynamic representations of co-created knowledge are implicated in virtual meetings based on multimodal, synchronous communication.*

VI. CONCLUSION

This research explains how communication practices with dynamic representations of co-created knowledge can enable repairs in virtual meetings. We demonstrated how the combined use of teleconferencing and collaborative mindmapping allowed three managers to interrelate and coordinate knowledge during a series of virtual meetings in the Comapping Project. As a result, we offered theoretical propositions that explain how communication practices with dynamic representations of co-created knowledge may be implicated in repairs during virtual meetings. In addition, we argued that dynamic representations based on multimodal communication can be investigated through a combination of quantitative and qualitative analyses of verbal acts, visual acts, and communication repairs.

Limitations

Designed as an explanatory case study, our research has notable limitations that call for caution when transferring findings to other contexts. First, many virtual meetings involve more participants than those in our study, and are therefore more complex. Increased complexity can make it more challenging for participants to dynamically represent the social system and thus more difficult to interrelate their actions. Second, the national culture of the Russian and Danish participants did not appear to significantly obstruct their ability to coordinate and communicate. Other studies show that national diversity may imply difficulties related to communication routines (Maznevski & Chudoba, 2000), linguistic differences (Kayworth & Leidner, 2000), and weak interpersonal relationships (Kraut et al., 1999). Hence, although the Comapping Project's meetings overcame differences in cultural knowledge, it is unclear whether this is transferable to other and more diverse cultural constellations. Also, the Comapping Project appears to involve significant levels of trust between participants, even while such conditions are difficult to establish in distributed organizations (Jarvenpaa, Shaw, & Staples, 2004; Jarvenpaa & Leidner, 1999; Kanawattanachai & Yoo, 2002). Third, the technology used in the Comapping Project's meetings was teleconferencing combined with collaborative mindmapping. The participants developed the mindmapping tool and they were therefore highly dedicated to multimodal, synchronous communication. While the specific technologies are available online for any distributed organization to explore, the relationship between meeting participants and technology may not be equally well aligned in other settings (c.f., Rice, Davidson, Dannenhoffer, and Gay's (2007) identification of significantly improved performance in virtual teams when team processes are adapted to the affordances of the applied communication technology).

Future Research

Further research is needed into how different communication practices based on different technologies afford dynamic representation of co-created knowledge and affect communication repairs in virtual meetings. Such studies could help us understand how communication repairs may be enabled with similar or radically different technologies. Virtual meeting size also raises interesting questions for future research concerning the complexity of more participants.

Cultural diversity remains a significant topic in research on coordination of distributed organizations (Huang & Trauth, 2008), and future research could help us understand better its interaction with and impact on virtual meetings. In particular, culture can play a role in articulating and interpreting communication acts (Fitch & Sanders, 1994; van Dijk, 1977), which may further extend to communication repairs in virtual meetings.

The communication study discipline describes and accounts for communication in fundamentally different ways (Grossberg, 1982). An interesting avenue for future research of dynamic representation in virtual meetings based on multimodal communication may rely on communication in Grossberg's (1982) term of "intersubjectivity as sociality". This view suggests that the individual is not an isolated consciousness, but constantly related and oriented to the environment. Consequently, the meaningfulness of the individual subject's experience is not describable in terms of collection of meanings created by and located in the mind. Rather, the subject is constantly engaged in processes of attempting to relate to the world and to others, and meanings are constituted in this continuous process by which the subject makes sense of and acts in the world (Grossberg, 1982).

The coordination challenges in virtual meetings may be further understood through the socio-cognitive lens of the collective mind as suggested by Yoo and Kanawattanachai (2001). Collective mind is a pattern of heedful interrelations of actions in a social system, where participants, understanding that the system consists of connected actions by themselves and others (representation), construct their actions (contributions) and interrelate them in the system (subordination) (Weick & Roberts, 1993). Fiore, Salas, Cuevas, and Bowers (2003) call for more detailed examinations of how a collective mind may be established over time and space in virtual contexts, but we still don't know to what extent it is possible to develop a collective mind through virtual meetings. Although research suggests this might be difficult (Anderson et al., 2007), studies have so far not investigated how dynamic representation of co-created knowledge based on multimodal communication may impact collective minding in virtual teams. We suggest communication repairs, verbal communication acts, and visual communication acts offer an intellectual perspective with an inherent focus on the heedful and heedless interrelating dialectic that is key in collective minding (Carlo et al., 2012).

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Editor's Note: The following reference list contains hyperlinks to World Wide Web pages. Readers who have the ability to access the Web directly from their word processor or are reading the paper on the Web, can gain direct access to these linked references. Readers are warned, however, that:

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