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INVITED PAPER

How do virtual teams process information? A literature review and implications for management

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Abstract

Purpose – The purpose of this paper is to inform readers on what is known on information processing in virtual teams and to discuss the consequences of these findings for the management of virtual teams.

Design/methodology approach – Systematic review of the literature on information processing in virtual teams based on a general information processing model for teams.

Findings – An overview of the most relevant factors that influence the effectiveness of virtual teams is provided.

Research limitations/implications – The review is based on existing literature on virtual teams and it discusses future research directions opened by the conceptualization of virtual teams as information processing systems.

Practical implications – The paper identifies the factors that can improve the effectiveness of information processing in virtual teams.

Originality/value – The general information-processing model for teams enables a systematic integration of the fragmented literature on virtual teams.

Keywords Information exchange, Virtual work, Communication technologies, Team working

Paper type Literature review

Virtual teams are nowadays a common form of organizing work. Organizations use virtual teams to innovate, make decisions or solve complex problems, tasks that heavily rely on information processing. Information processing in virtual teams depends on the interplay between the individual cognitions of team members and team interaction processes (Curşeu *et al.*, 2007). The virtual character of the communication processes has important implications for the dynamics of virtual teams and therefore for the way they process information. The basis for this article is an integrative model for information processing in virtual teams. The model serves as a framework to integrate the theoretical arguments and the empirical results concerning the impact of communication technology on team effectiveness in cognitive tasks (tasks that require information processing).

First, we address the main typologies of virtual teams as well as the reasons for using virtual teams in organizational settings. Second, we describe the general information-processing model for teams, and use it further on to integrate the literature on information processing in virtual teams. Finally, we discuss the theoretical and practical implications of this systematic review of the literature.

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Virtual teams: a general framework

A commonly used and generally agreed upon definition of virtual teams is difficult to find. This has to do with the fact that virtual teams have many forms, differing objectives, different membership criteria, organizational affiliations, task types, and so on (Zigurs, 2003). As a result, research has focused on many different team characteristics associated with virtual work, and produced a variety of idiosyncratic definitions of virtual teams.

The degree of interaction and interdependence between the team members is the first dimension on which definitions of virtual teams may differ. This draws on the basic conceptual distinction between the concepts of "team" and "group". Some scholars use virtual teams and virtual groups as synonyms (e.g., Lipnack and Stamps, 1997; Townsend *et al.*, 1998). For Towsend *et al.* (1998), the term virtual team refers to groups that are geographically and/or organizationally dispersed, are linked by telecommunication and information technology, and rarely, if ever, meet face-to-face. For others, virtual teams have more interaction and greater interdependence between team members, than virtual groups (Furst *et al.*, 1999). With respect to the degree of interaction, in the present paper, we take a more generic stance and consider virtual teams/groups as socio-technical systems.

A second dimension on which there is no consensus in the literature is whether virtual teams are temporary or permanent. Kossler and Prestridge (1996) state that virtual teams are brought together to focus on a specific project with a specified ending date (virtual teams as temporary work arrangements). Kristof *et al.* (1995) explicitly state that, in their view, a virtual team is always temporary. They define virtual teams as self-managed knowledge work teams, composed of members with different areas of expertise, formed to accomplish a specific organizational goal within a specified period of time (Kristof *et al.*, 1995). Others state that virtual teams can be temporary when they are set up for a specific task, or permanent, such as a strategic planning team (Lipnack and Stamps, 1997; Townsend *et al.*, 1998). Our focus here is rather the cognitive character of the task and not the duration of the team project. We assume that information-processing mechanisms in virtual teams are universal and the duration of the task, has only a moderating role in the relationship between virtuality and team effectiveness.

The extent to which teams rely on technology to communicate is another dimension on which virtual teams scholars disagree. For some, the term "virtual teams" refers to teams that exclusively interact through electronic media. This approach excludes teams that sometimes meet face-to-face (e.g., Bouas and Arrow, 1996; Canney Davidson and Ward, 1999; Kristof *et al.*, 1995). However, most of the scholars, agree that virtual teams can use face-to-face communication, as long as most of the time, team members use communication technology (e.g., Jarvenpaa and Leidner, 1999; Maznevski and Chudoba, 2000; Townsend *et al.*, 1998). An important issue, linked to the use of communication technology, is the distinction between synchronous and asynchronous communication. Synchronicity describes the capability of a communication tool to concurrently engage all team members in the communication event (Carlson and George, 2004, p. 192). Media with a high degree of synchronicity allow the participants to communicate in real time (e.g., video or phone conference). Differences in temporal synchronicity influence the effectiveness of a virtual team (Montoya-West *et al.*, 2001; Kirkman *et al.*, 2004). We will argue that synchronicity is a core factor influencing the knowledge integration in virtual teams.

Finally, there is a distinction between virtual teams and global virtual teams. Global virtual teams are teams composed of members with diverse cultural backgrounds, and spanning over different geographical locations or nations (DeSanctis and Poole, 1994; Jackson *et al.*, 1995; Kristof *et al.*, 1995; Jarvenpaa and Leidner, 1999). Virtual teams are comprised of individuals who are in general culturally similar and have a moderate level of physical proximity (McDonnough *et al.*, 2001; Montoya-Weiss *et al.*, 2001). Heterogenity (in particular team diversity as variety) is beneficial for the development of complex knowledge structures, an essential aspect of information processing in teams (Curşeu *et al.*, 2007)

Definitions of virtual teams use therefore many dimensions, therefore creating a general, comprehensive, and useful taxonomy of virtual teams is needed, but difficult to achieve. Any attempt to integrate all the dimensions will inevitably produce a multidimensional and incomprehensible framework that is difficult to use in practice. Nevertheless, various approaches share, according to Martins *et al.* (2004), several similarities. It is generally accepted that virtual teams are socio-technical systems composed of:

(1) two or more persons, who

(2) collaborate interactively to achieve common goals, while

(3) at least one of the team members works at a different location, organization, or at a different time, so that

(4) communication and coordination is predominantly based on electronic communication media (e-mail, fax, phone, video conference, etcetera) (Martins *et al.*, 2004; Hertel *et al.*, 2005).

There are two main reasons for the growth of virtual teamwork, and the use of communication technology in organizations. First, the emergence of virtual teams was a response to various challenges organizations of the 21st century faced and still face. Rapid changes in the business environment, globalization of the marketplace, a growing popularity of inter-organizational alliances combined with a tendency to design more flexible and versatile organization structures, has accelerated the need for organizations to coordinate work across geographical, functional, intra- and interorganizational as well as temporal boundaries (Armstrong and Cole, 1995; Lipnack and Stamps, 1997; Townsend *et al.*, 1998). Second, the rapid development of communication technology during the last decades, made the distribution and the coordination of work much easier and much faster across time and across different geographical locations (Montoya-Weis *et al.*, 2001; Kirkman *et al.*, 2004; Hertel *et al.*, 2005).

Therefore, communication technology facilitates the transfer and use of knowledge across time and space. As a consequence, virtual teams perform a wide variety of tasks like: new product development (Schmidt *et al.*, 2001), decision-making (Poole *et al.*, 1993; Dennis, 1996; Warkentin *et al.*, 1997; Benbunan-Fich *et al.*, 2002), brainstorming and idea generation (Pissarra and Jesuino, 2005), implementation of inter-organizational alliances (Maznevski and Chudoba, 2000), the development of marketing strategies (Montoya-Weiss *et al.*, 2001), and elaboration of business plans (Jarvenpaa *et al.*, 2004). In contemporary organizations, virtual teams mostly perform information-processing tasks like decision-making and problem solving (Martins *et al.*, 2004; Hertel *et al.*, 2005). The use of communication media implies important

managerial challenges, because it induces radical changes in team processes (e.g., coordination, planning), the development of the emergent states (e.g., trust, team identity, cohesion), status differences and leadership.

Although enlightening for the variety of virtual teams used in organizations, typologies and classifications proposed in the literature did not enrich our understanding of information processing in virtual teams. In order to integrate the diverse approaches another framework is needed. Some authors (Furst *et al.*, 1999, Martins *et al.*, 2004) already used a systemic approach (an input-process-output model) to integrate the literature on virtual teams. There is no systematic comparison however, concerning the information processing mechanisms between virtual and face-to-face teams. We use a cognitive architecture model for teams to guide this comparison. This approach is in line with the science's general aims to develop unified explanatory theories (Newell, 1990), and in this paper a specific model of information processing in groups is used to understand the factors that affect information processing in virtual teams and to explain the differences in information processing between virtual and face-to-face teams.

A model for information processing in teams

Before we compare information processing in virtual teams and face-to-face teams we first need to identify a general theoretical approach, which explains the basic information processing mechanisms in teams (as socio-cognitive systems) Faced with various circumstances, how does a team use information at hand to arrive at a particular decision or solution to a problem? In the last decades, several attempts have been made to identify and define the mechanisms of team information processing on a variety of tasks. There have been only a few attempts, however, to develop a unified theory on information processing in groups (see for exceptions Hinsz *et al.*, 1997; Curşeu, 2003, 2006).

A comprehensive way of analyzing information processing in a group is to conceptualize a group as a socio-cognitive system, and to use the concept of "cognitive architecture" to explain the functioning of the system (Newell, 1990). The concept of cognitive architecture emerged from a general and integrative theoretical approach that underlines the mechanisms by which information is processed in a cognitive system. The concept explains the ways in which cognitive systems processes information by integrating aspects that remain relatively constant over time and are task-independent (Newell, 1990; Howes and Young, 1997; Gray *et al.*, 1997; van Gelder, 1998; Anderson and Lebiere, 1998). Since information-processing mechanisms are general, the framework of cognitive architecture serves in explaining performance in different types of (virtual) teams, regardless of the specific tasks they perform.

The concept of cognitive architectures emerged in the early 1990s. The concept enabled the integration of human information-processing theories and guided subsequent empirical research on human information processing – leading to an exponential growth in studies in the last decade (Anderson and Lebiere, 1998; Byrne, 2001). Moreover, the development of cognitive architectures had implications in applied settings, especially related to the analysis of and solutions for human-computer interaction problems (Howes and Young, 1997; Byrne, 2001).

Hinsz *et al.* (1997) provide an integrative model that describes the general characteristics of information processing in groups. This model was the first to

describe the manner in which groups-as-a-whole process available information. It refers to general mechanisms of information processing, and thus comes close to the concept of cognitive architecture. Although the authors do not explicitly use the term cognitive architecture, the model does specify invariable mechanisms by means of which groups process available information.

The first information-processing step in the model is the attention phase in which groups select information that is available in the environment. Groups further process this information according to objectives embedded in the environment. This information processing takes place in the so-called "processing workspace" and consists of three processes: encoding (i.e. forming knowledge representations through interpretation, evaluation and transformation), storing (i.e. entering representations in the memory system), and retrieval (i.e. accessing and using representations from the memory system). In other words, groups receive, store and, most importantly, integrate information, to use it for their task performance, based on certain rules, strategies and procedures (Hinsz *et al.*, 1997).

Another integrative model of information processing in teams (Gibson, 2001), discerns four stages of information processing: accumulation, interaction, examination and accommodation. During the accumulation stage, groups gather information and knowledge by perceiving, filtering and storing. Groups label and categorize pieces of information discussed by the members. One way of labeling is creating jargon (e.g., words, phrases, or gestures that only have meaning for the group members). To use the group knowledge, the group should be able to retrieve, exchange, and structure information. All this takes place in the interaction stage.

The examination stage consists of negotiating, interpreting and evaluation of knowledge by the group members. Examination then gives rise to accommodation, a stage in which the perceptions, judgments and opinions of group members are integrated, generating decisions and actions (Tuckman and Jensen, 1977; Von Cranach *et al.*, 1986; Goodman *et al.*, 1990; Gibson, 2001).

Gibson (2001) argues that these stages do not occur in a linear time order. Several factors influence the bridging of stages. For example, as a result of the knowledge accumulation process, the group may either go to the interaction stage, or straight to the accommodation stage. If the accumulated knowledge is highly ambiguous, implying uncertainty about the group's task, the group will first go through the interaction and examination stages. During these stages, the group verifies the assumptions and seeks for new information that solves ambiguities and uncertainties. If the accumulated knowledge is clear and structured and the task routine, well structured, and clearly defined, the group is likely to go from the accumulation stage straight to the accommodation stage (Gibson, 2001).

Gibson (2001) elaborates the role of leadership and group interaction in relation to the different stages. Leadership can have a prominent facilitating role in information processing in a group. Passing from the interaction to the examination stage is easier when there is an effective leader who guides and coordinates (Gibson, 2001). Leaders can guide the group through the transition to the examination stage by interpreting knowledge and by solving conflicts that may occur in the group. On the other hand, role ambiguity often results in regression to the accumulation stage. A clear definition of roles in the group fosters knowledge sharing: when the group members know each other's abilities, they will know where to find a specific ability or specific information.

Role ambiguity occurs more frequently in groups that do not have a leader, or have a "*laisser-faire*" type of leadership. An efficient leader reduces role ambiguity in the group to facilitate reaching the knowledge examination stage (Gibson, 2001).

Group interactions are important during the knowledge examination stage. If these interactions end up in conflicts, the group falls back to the interaction stage where new knowledge is retrieved, transferred, exchanged and structured. If the interactions lead to consensus, the group passes on to the accommodation stage, where knowledge is integrated and leads to decisions or actions (Gibson, 2001).

Nonaka and Takeuchi (1995) propose a different approach of information processing. Their focus is on the organizational level, and can be extended to a certain extent to the group level. The authors distinguish between explicit and tacit knowledge. Based on the way these two types of knowledge are transformed they describe four ways of knowledge processing: socialization, externalization, combining and internalization (Nonaka, 1994; Nonaka and Takeuchi, 1995; Nonaka *et al.*, 1998; Nonaka *et al.*, 2000). Socialization is the knowledge sharing process through which implicit knowledge passes from one group member to another or from one group to another. Since it is difficult to externalize, tacit knowledge transfer takes place through direct interactions. Therefore, direct experience and interaction are the only ways in which tacit knowledge can be transferred from one individual or group to another (Nonaka *et al.*, 1998; Nonaka *et al.*, 2000). Externalizing knowledge means articulating tacit knowledge, and making it possible to express. In other words, the externalization process turns tacit knowledge into explicit knowledge. Externalizing tacit knowledge occurs when using analogies, comparisons, or metaphors. The combining process refers to the integration of explicit knowledge in order to generate new explicit knowledge. The group uses such new knowledge to solve problems, make decisions or implement them in the organization in order to be used by other groups. Internalization means turning explicit into implicit knowledge. For example, procedures used to make a new product are at first presented explicitly; the group internalizes them over time, turning them into implicit knowledge (Nonaka, 1994; Nonaka and Takeuchi, 1995; Nonaka *et al.*, 1998; Nonaka *et al.*, 2000).

Curşeu (2003) proposed an integrative cognitive architecture model for groups that integrates the previously described models to explain how groups process information. This integrative model describes information processing in groups as the interaction between three subsystems: selection, memory and communication (see Figure 1). Teams are cognitive systems, in which three subsystems interact: the selection subsystem, the memory subsystem and the communication subsystem. The groups select part of the available information, represent it in a specific manner, and transform these representations generating specific outcomes. The communication subsystem has a crucial impact on the manner in which groups form certain representations of knowledge and transform these representations into specific outputs.

The central characteristic of collective representations of groups is that they are distributed across the group members. Because of this distributed character, the communication patterns and interactions between the group members play a prominent role in forming and transforming these representations (Curşeu, 2006; Curşeu *et al.*, 2007). The representations can be transformed by means of processes such as: accumulation, interaction, examination, accommodation (Gibson, 2001), as well as internalization, externalization, socialization and combination (Nonaka and Takeuchi, 1995).

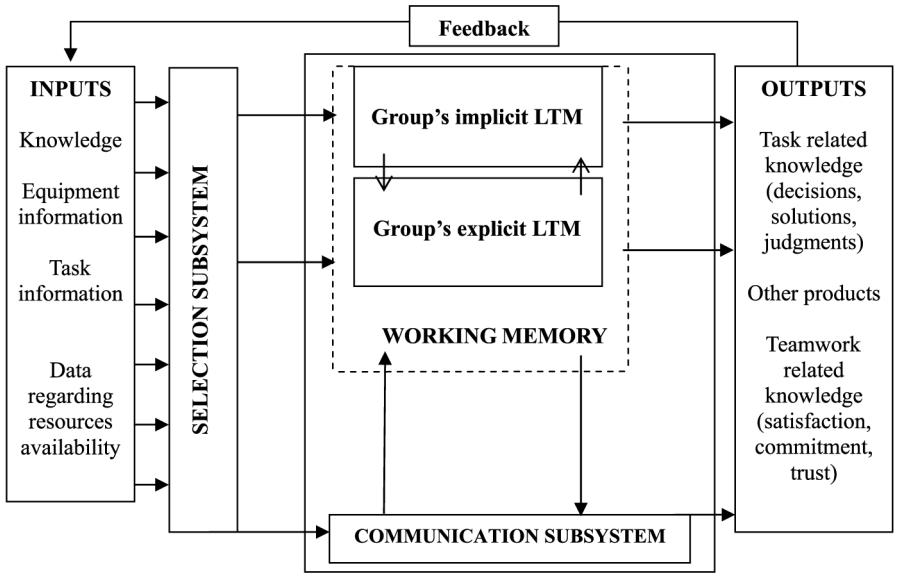

Figure 1.
A cognitive architecture model for virtual teams

Key: LTM = long term memory

Source: Adapted from Curşeu (2003)

Curşeu's (2003) approach is an integrative socio-cognitive approach. The model shows that the social interaction processes in a group determine the way in which groups represent knowledge and transform representations into specific outputs (see also for empirical tests, Curşeu *et al.*, 2007; Curşeu and Schruijer, n.d.). The interaction between communication and group memory is especially important for virtual groups: the way of communicating of the virtual group impacts the team's memory system. This general model serves as a framework to describe the information processing differences between virtual and face-to-face teams. The functional differences between the two types of teams will be discussed for all the subsystems described in the model. The basic functioning of the selection subsystem explains the differences between face-to-face and virtual teams in idea generation, brainstorming and creativity. The memory system explains the disparity between virtual and face-to-face teams with respect to the development of shared task understanding, transactive memory, and knowledge integration, while the interaction between memory and communication subsystems explains the differential use of implicit versus explicit knowledge in virtual and face-to-face teams.

The selection system and selection biases

Information processing in groups is a complex process, susceptible to many biases and errors (Curşeu, 2006). An important type of bias is selective information processing: the group does not process all the available information. The selectivity of information processing depends on social factors such as group norms, group interaction, and the group's social environment, and, in addition, by cognitive factors, such as the

information distribution and information availability in the group. These selection biases can lead to group inefficiency, and sometimes even have disastrous consequences (see the consequences of groupthink).

One of the most important factors affecting the selection of information is the distribution of information between the members of a group. According to the so-called "Information Sampling Model" (Stasser and Titus, 1985; Stasser, 1988), groups discuss and use mainly common information that shared by all group members. This is a selection bias with a strong negative effect on information processing, because it hinders access to the total pool of knowledge of the group (Curşeu, 2003). Moreover, it should be noted that the contributions of group members to group discussions is not equal and it follows a power law distribution, with only a few members contributing a lot and most of group members contributing less to groups interactions (Curşeu, 2006).

In virtual teams, the minority influence (i.e. the use of unique information) has a stronger influence (Dennis *et al.*, 1998). The "information sampling" effect is less strong in virtual than in face-to-face teams. The explanation for this phenomenon is probably that there is a lower normative pressure in virtual settings (Nunamaker *et al.*, 1996), because the virtual communication environment reduces the exchange of social cues. These cues implicitly pressurize the minority to conform to the shared views of the majority (Hollingshead, 1996). The consequence is that in virtual groups it is easier to use a large pool of knowledge. Whether this ensures better performance is open to discussion.

The literature on electronic brainstorming sheds some light on this issue. Virtual groups are superior to face-to-face groups in terms of the quantity of ideas generated in group meetings (Dennis *et al.*, 2001; Kerr and Murthy, 2004). Baltes *et al.* (2002) reported in a meta-analysis of studies on group effectiveness that computer-mediated communication (CMC) generates a higher number of alternatives than face-to-face (FTF) communication. An important variable in this respect is anonymity. Anonymity decreases the pressure to conform and therefore allows group members to more freely express their ideas. According to Baltes *et al.* (2002), there is less risk of embarrassment for expressing personal ideas when the group members are anonymous. In addition, all the ideas are evaluated on their merit rather than on the status of the person who presented the ideas.

However, even when the amount of information discussed by a group is greater when there is anonymity, this is still not a guarantee for enhanced performance of the group. When the task is performed under time pressure, when the participants are not anonymous, and when the task can be characterized as intellective or mixed-motive, CMC groups perform worse than those using FTF communication. In addition, anonymous groups using CMC need more time to come to a decision than anonymous groups using FTF communication. Moreover, groups using CMC were less satisfied compared to those using FTF communication in intellective and mixed-motive tasks. Nevertheless, when there was unlimited time to reach consensus there were no differences in satisfaction between groups using CMC or FTF communication (Baltes *et al.*, 2002). Computer mediated communication facilitates idea generation in virtual groups, especially when the contributions are anonymous.

Virtual teams have higher team creativity, defined as the quantity of ideas generated (Garfield *et al.*, 2001). Idea generation, however, is only one component of the creative process. Creativity also implies novelty, applicability, appropriateness, usefulness and correctness (Amabile, 1983).

Dennis *et al.* (2001) showed in a meta-analysis of studies that there are no significant differences in decision quality between virtual teams and other teams. Although the number of ideas generated by virtual teams is significantly higher, this does not seem to make virtual teams more creative, nor to improve the quality of their decision-making. The time spent in generating decision alternatives is the least important predictor for the effectiveness of group decision-making (Orlitzky and Hirokawa, 2001).

A similar result is found for information biases in information processing. Virtual teams are less susceptible to information biases, and still decision quality is not better than in face-to-face teams (Poole *et al.*, 1993; Dennis *et al.*, 2001). The explanation for these paradoxal results could be the lack of knowledge integration (Dennis, 1996; Alavi and Tiwana, 2002) in teams using virtual communication. Knowledge integration relates to the functioning of the memory system of a group, which will be discussed in the following section.

The memory system and information processing

Memory processes at the group level are distributed across different individuals (Ostrom, 1989; Wegner *et al.*, 1991). The conceptualization of memory as a social phenomenon is the core of the transactive memory model for groups. Wegner proposed this model in 1987, and it was later used in studies to explain coordination behavior of intimate couples. In the last decade the model has been applied to groups in work settings (Liang *et al.*, 1995; Moreland *et al.*, 1998; Moreland, 2000).

Wegner *et al.* (1991) refer to the collective memory of a group as a shared system for "encoding, storing and retrieving information". The model discerns two types of knowledge representation: information stored by the group members in their individual memories and a memory system with information on what each group member knows. This system allows the group members to identify the existence, location and means of retrieval for the information held by other group members (Wegner *et al.*, 1991). In other words, group members use each other as external memory units in addition to their own (limited) memory capacity.

According to Alavi and Tiwana (2002), virtual communication imposes constraints on the transactive memory system. The indirect interactions between the team members, the physical distance, the lack of collaborative history as well as the high diversity of knowledge and expertise in virtual teams hinders the development of the transactive memory (Alavi and Tiwana, 2002). Virtual teams have a weaker transactive memory, and the integration of relevant information held by the individual team members often lacks consistency. The idea that face-to-face teams make better use of information and integrate information more efficiently than virtual teams is supported by several studies (Dennis, 1996; Baltes *et al.*, 2002; Kerr and Murthy, 2004). The lack of integration of information in virtual teams is also related to the stages of information processing as discussed by Gibson (2001, see above).

The interaction and examination stages are essential for the integration of information. Factors such as task uncertainty, role ambiguity, effective leadership, and conflict, have an effect on the integration of information in these stages (Gibson, 2001). Virtual teams spend more time on task orientation, and experience higher levels of role ambiguity and task uncertainty compared to other teams (Poole *et al.*, 1993; Nunamaker *et al.*, 1996; Zigurs, 2003). This explains the deficits experienced by virtual teams in the interaction and examination stages of information processing.

On the other hand, although virtual teams can exchange verbal information as efficiently as other teams, their ability to handle non-verbal information is very limited. This can lead to an increase in misunderstandings between the team members (Warkentin *et al.*, 1997), and increases chances of conflict. Furthermore, diversity is likely to be high in virtual teams because team members from different geographical locations represent different cultures, nations or functions. Therefore, the degree of conflict in virtual teams is often higher than in face-to-face teams (Milliken and Martins, 1996).

Another factor that plays a prominent role in the interaction and renegotiation stages of information processing in teams is leadership. Effective leadership is often difficult to achieve in virtual teams (Zigurs, 2003; Cascio and Shurygailo, 2003). Difficulties related to leadership, role ambiguity, task uncertainty, and, many conflicts in virtual teams are likely to have a negative effect on the interaction and examination stages of information processing in the team. Therefore, it is expected that virtual teams will have difficulties related to efficiently exchanging information, structuring it, and in interpreting and evaluating knowledge. In short, this reflects a lack of informational integration.

The representations formed in the team's working memory play a pivotal role in team performance. Especially the number of simultaneously activated representations is a critical issue with respect to the integration of information. This refers to the concept of memory interference in teams. When performing cognitive tasks, teams use significantly more information than their individual members do. The larger the amount of information analyzed and processed, the higher the team performance. Team characteristics, team dynamics and the communication environment influence memory interference in teams. Memory interference is higher in heterogeneous teams, and in larger teams (Curşeu, 2003). The communication environment influences memory interference in teams as well. As noted above, the use of technology directly influences the amount of information discussed by a team (Valacich *et al.*, 1992; Hollingshead and McGrath, 1995; Valacich and Schwenk, 1995; Zigurs, 2003). Therefore it is expected that memory interference will be higher in virtual teams than in other teams. In principle, higher memory interference is beneficial for integration. In virtual teams, however, due to less effective team processes, the higher memory interference cannot be mastered effectively. Therefore, the integration of information in virtual teams is sub-optimal. Other factors that influence the memory interference in virtual teams (as in other teams) are team composition and team dynamics. Because the use of communication technology affects team dynamics and virtual teams are often more diverse than face-to-face teams, it is likely that the use of IT has also an indirect impact on information processing in virtual teams.

Several studies have shown that team characteristics are closely related to the use technology-mediated communication, in the sense that virtual teams are more heterogeneous on a variety of aspects than other teams (Tan *et al.*, 1998; Potter and Balthazard, 2002). Both the use of technology (Kirkman *et al.*, 2004; Fiol and O'Connor, 2005), and team characteristics (Milliken and Martins, 1996) influence team dynamics and therefore influence information processing in teams.

According to the categorization-elaboration model (van Knippenberg *et al.*, 2004) team diversity is positively related to the elaboration of task relevant information. At the same time, however, diversity fosters the social categorization process in teams.

Virtual teams are often more diverse, as well in directly observable characteristics, such as gender, age, and race, as in "hidden" attributes, such as knowledge, skills and abilities, personality, and organizational tenure. This diversity has opposing effects on team effectiveness. First, a diverse team can benefit from the diversity of perspectives brought in by the team members, which leads to increased elaboration of task relevant information. On the other hand, stereotyping as a consequence of the social categorization process can have a negative impact on team performance because it fosters relationship conflict (van Knippenberg *et al.*, 2004).

An important issue in this respect is the role of communication technology. Will the use of technology enhance the elaboration of task relevant information or will it foster the social categorization process? Technology limits the number of para-verbal cues exchanged by virtual team members during their interactions. The number of para-verbal cues exchanged depends on the type of technology used. Even in videoconferencing, fewer cues are exchanged than in face-to-face interaction. The cues are essential for the building of trust and commitment in social relations. In addition, they play a role in the social categorization processes. The para-verbal cues are the first cues that trigger the social categorization process. Observable characteristics such as gender, age, and race automatically trigger the activation and use of stereotypes.

A positive aspect is that communication technology can provide the opportunity for equal participation of every member of the team. Because communication technology excludes the effects of differences in status that are triggered by cues like appearance, presence, vocal inflexion, and so on (Zigurs, 2003), there is a positive effect on the number of alternative solutions generated as well as the performance on brainstorming tasks (Valacich *et al.*, 1992; Valacich and Schwenk, 1995; Pissarra and Jesuino, 2005).

Hollingshead and McGrath (1995) confirm that computer-mediated teams are more effective in brainstorming. Nevertheless, they conclude from their review of the literature, that decisions made by computer-mediated teams are inferior compared to face-to-face teams because they take longer, because less information is exchanged per unit of time, and because the satisfaction of team members is rather low (Hollingshead and McGrath., 1995). Time pressure, however, is not the main criterion to evaluate the effectiveness of problem solving and decision-making. The greater information pool that is available in virtual teams will certainly affect the team's working memory. Increased memory interference stimulates the elaboration of task relevant information and improves performance.

On the other hand, technology has negative influences on planning and coordination. According to Hollingshead *et al.* (1993), novel technology combined with a lack of experience in using communication technology, hinders planning and coordination activities, and negatively influences team performance. Virtual teams need more time for decision making because the team members are less able to make inferences about each other's knowledge (defective transactive memory) and to anticipate each other's reactions. This will have an impact on the memory processes of a team.

A second negative effect of communication technology is that it makes the development of trust and team identity more difficult. In virtual teams, both social cues are more difficult to communicate as well as communication cues that individuals use to build trust, warmth, attentiveness, and other important interpersonal affections that foster group cohesion (Jarvenpaa and Leidner, 1999; Jarvenpaa *et al.*, 2004). Another

factor related to the development of trust within virtual teams is leadership. The drawbacks of communication technologies especially for transformational leadership hinder the development of trust in virtual teams (Gillespie and Mann, 2004). Team identity is difficult to develop in virtual teams leading to a low within team cooperation and a low commitment of the team members with the team. This has a negative impact on team performance. Both laboratory and field studies showed that in virtual teams team identity is less developed compared to face-to-face teams (Bouas and Arrow, 1996; Warkentin *et al.*, 1997, Fjermestad and Hiltz, 2000).

A third negative effect is the impact of communication technologies on intrateam conflict. Virtual teams are inherently diverse and the probability of experiencing both task and relationship conflict is higher in diverse than in homogeneous teams (Jehn *et al.*, 1999). On the one hand task conflict can be beneficial for team performance, when it occurs in the initial stages of group development (Jehn and Mannix, 2001) and when it is associated with high levels of trust and does not degenerate into relationship conflict (Simons and Peterson, 2000). On the other hand, relationship conflict can have a negative effect on team effectiveness, team members' satisfaction and well-being (Jehn *et al.*, 1999; Medina *et al.*, 2005; Passos and Caetano, 2005). Since the level of trust within virtual teams is low, one might expect that task conflict has higher chances to evolve into relationship conflict.

Virtual team performance depends on several factors that are influenced by technology, such as: the quality of communication (Maznevski and Chudoba, 2000; Kayworth and Leidner, 2000; Sproull and Kiesler, 1986), planning and project management (Kayworth and Leidner, 2000), coordination (Maznevski and Chudoba, 2000), developing a shared context (Hinds and Bailey, 2003), trust (Jarvenpaa and Leidner, 1999; Jarvenpaa *et al.*, 2004; Kanawattanachai and Yoo, 2002), commitment with the team and team members' satisfaction (Caballer, Gracia and Peiró, 2005), team identity development (Bouas and Arrow, 1996, Warkentin *et al.*, 1997, Fjermestad and Hiltz, 2000), training and team building (Kaiser *et al.*, 2000; Warkentin and Beranek, 1999), and cohesion (Lurey and Raisinghani, 2001; Maznevski and Chudoba, 2000). In order for technology to foster team performance, it should enable proper social interactions between the team members and fit the requirements of the task.

The central principle of virtual team effectiveness according to the task-technology fit theory is that there should be a fit between the task requirements and the potential of technology to enable interactions between the team members (Daft and Lengel, 1984; Zigurs and Buckland, 1998; Warkentin and Beranek, 1999; Dennis *et al.*, 2001; Maruping and Agarwal, 2004). Task-technology fit is defined as the degree to which communication technology assists an individual or group in effectively performing a task (Goodhue and Thompson, 1995; Maruping and Agarwal, 2004). A better match between the task and technology leads to better outcomes at the team level. Empirical results confirm this argument (Maruping and Agarwal, 2004). When the IT functionalities match the communication requirements and the interpersonal processes in the team, team performance is better. The effectiveness of information transfer and the use of information in teams is determined by the ability of the communication channels to transfer information. In the same vein, media richness theory suggests that communication tools that are able to help the group members to clarify the ambiguity of the messages that are transmitted are more effective (Maruping and Agarwal, 2004). A better fit between task and technology, as well as the use of communication tools

that allow for a rich information echange among team members lead to a higher virtual team effectiveness as well as an increase in satisfaction, team cohesion, and team commitment (Curşeu, 2006, Dennis *et al.*, 2001; Maruping and Agarwal, 2004; Caballer *et al.*, 2005; Rico and Cohen, 2005). The communication environment therefore directly influences the ability of virtual teams to integrate information.

In summary, virtual communication has a strong influence on group memory. First, the use of virtual communication has a direct positive influence on memory interference and the elaboration of task relevant information. Second, the use of virtual communication has disruptive effects on team dynamics (coordination, planning, leadership effectiveness, trust, cohesion) and because of that a negative impact on the integration of information. Virtual teams benefit from the higher memory interference and the higher elaboration of task relevant information, but only to the extent to which the disruptive effects technology mediated communication are controlled for and reduced.

Communication and information processing

Information processing in groups is the result of social interactions between the group members. Therefore, communication has a central role in information processing. According to the functional theory of group decision-making (Gouran *et al.*, 1992; Orlitzky and Hirokawa, 2001), group effectiveness in decision-making or problem solving tasks is contingent on the interaction between the group members (Hirokawa, 1988, 1994; Orlitzky and Hirokawa, 2001). When groups want to reach high quality decisions, interpersonal interactions and communication have to meet the following five criteria:

(1) *Problem analysis.* The group must develop a thorough and accurate understanding of the problem by analyzing its nature, severity and extent as well as the most likely causes of the problem and the possible consequences of not dealing effectively with it.

(2) *Establishing the evaluation criteria.* The group must achieve an appropriate understanding of the requirements for an acceptable choice.

(3) *Generating alternative solutions.* The group must identify, and if necessary develop a set of realistic and acceptable alternatives.

(4) *Evaluation of positive consequences associated with alternative choices.* The group must assess thoroughly and accurately the positive consequences associated with alternative choices.

(5) *Evaluation of the negative consequences of solutions.* The group must evaluate thoroughly and accurately the negative consequences associated with alternative choices (Hirokawa, 1994; Orlitzky and Hirokawa, 2001).

In a meta-analysis Orlitzky and Hirokawa (2001) analyzed empirical evidence supporting this functional perspective on small group decision-making. Their results suggest that the most important function is the evaluation of negative consequences for alternative solutions. The effect of communication on the effectiveness of group decision-making is moderated by task contingencies. For example, the assessment of negative consequences appears to be more important when the group has to decide between multiple acceptable choices, when there are no obvious evaluation criteria

available, and when it is not possible to objectively verify all the possible outcomes of the choices. In conclusion, the evaluation of the possible negative consequences of choosing a certain alternative is a good predictor for the effectiveness of group decision-making in complex situations.

The communication system is essential for the way knowledge is represented and organized in the group's memory system. The integration of information is better in groups communicating face-to-face than in virtual groups. However, when communication technology allows for richer information transfer between the team members (e.g., in videoconferencing), the differences are small. It is clear that a good fit between the task and the communication technology leads to better knowledge transfer and better integration of knowledge.

The greater pool of knowledge in virtual teams than in face-to-face teams can be explained by the interaction between the communication subsystem and the selection subsystem. Since the pressure towards conformity is lower in virtual teams, the contribution of ideas of members to the discussion in the group is greater (Parent *et al.*, 2001), an illustrative fact for the interaction of the two systems in virtual teams.

The interaction between the memory subsystem and the communication subsystem

Communication is the main process that activates knowledge representations and transfers information from the team's long-term memory to the team's working memory. A cognitive collective representation developed through social interactions and stored in the long-term memory can be activated and transferred to the team's working memory through communication. Therefore, the interaction between communication and memory is essential for the development and use of cognitive representations on the group level, or in other words for the integration of information.

The communication process in virtual teams is fundamentally different from that in other types of teams, due to the use of technology. Two aspects are of particular importance in this respect: the role of the communication environment in the transfer of implicit and explicit knowledge between the team members, and the implications of the communication environment for the activation of collective representations in the team's working memory.

Teams can use two types of knowledge in decision-making and problem solving tasks: explicit knowledge and implicit knowledge (Nonaka and Takeuchi, 1995; Nonaka *et al.*, 1998). There are two reasons why this implicit-explicit knowledge distinction is important for information processing in teams. In the first place, the transfer of the two types of knowledge between the team members takes place in different ways. The second reason is that the use of implicit and explicit knowledge changes in the different stages of team performance. Shared implicit knowledge is used more frequently during the first stages of the team discussions. Social stereotyping and social categorization processes are triggered at the beginning of team interactions (Curşeu, 2003).

Empirical studies on information processing in teams mainly focused on explicit knowledge. The role of implicit knowledge was hardly addressed. Many theories on team decision-making and problem solving incorporate the use of explicit knowledge. This type of knowledge has obvious importance. Rational reasoning is based on this type of knowledge, and at the same time, the knowledge is used to create arguments

supporting the different options. However, the role of implicit knowledge should be taken into account too.

Transmitting knowledge and using it are interdependent processes. Implicit knowledge is best transmitted in direct interactions between the team members (Nonaka and Takeuchi, 1995). This type of interaction is only possible in face-to-face communication. During these types of interactions, nonverbal cues complement the explicit information put forward by the team members. The transfer of para-verbal cues in computer-mediated communication is limited, which makes it difficult to use implicit knowledge in decision-making or problem solving (Hwang and Guynes, 1994; Hightower and Sayeed, 1996; Warkentin *et al.*, 1997; Hedlund *et al.*, 1998; Baltes *et al.*, 2002).

There are several types of implicit knowledge that can be used by teams. Two types of implicit knowledge are especially important for virtual teams: shared social implicit knowledge (e.g., stereotypes and attitudes) and explicit knowledge that was made implicit through practice or internationalization processes (Nonaka and Takeuchi, 1995). Initial explicit rules for coordination between team members can become shared implicit knowledge. Knowledge related to teamwork has an implicit character and, as has been shown several times, influences the general performance of a team (Cannon-Bowers *et al.*, 1993; Sosik *et al.*, 1998; Mathieu *et al.*, 2000; Curşeu, 2003).

Another specific characteristic of virtual teams is that they use external memories to a greater extent than other teams. Decision support systems and expert systems are usually associated with the use of communication technology (Nunamaker, 1997; Alavi and Tiwana, 2002). Expert systems and decision support systems are "external" memories in which organized expert knowledge is stored. Virtual groups can better benefit from and use this knowledge since technology-mediated communication is often associated with the use of decision support and expert systems. When virtual teams use these memories, the limitations of communication technology to transfer implicit knowledge can to a certain extent be mitigated, because in the externalized expert knowledge systems implicit knowledge is stored in an explicit fashion.

Summary of the literature review

Communication technology affects information processing in virtual teams in two ways. First, there is a direct effect of communication technology on the knowledge pool and the use of knowledge in virtual teams. Second, virtual communication has an indirect effect on the way teams process information, because the communication environment influences team processes, the emergence of trust and cohesion, and information processing capabilities. Table I summarizes the main differences between virtual and face-to-face teams, related to the use of information technology.

Virtual teams are better in exchanging information and in overcoming information biases. However, they encounter problems in using and integrating information. A greater pool of knowledge leads to higher memory interference in virtual teams. Nevertheless, in virtual teams, processes such as planning and coordination, are less effective and the emergence of trust and cohesion is more difficult to achieve. These opposing effects limit the potential of better knowledge integration in virtual teams.

Coordination is of utmost importance in virtual teams. Virtual teams often have to deal with complex coordination problems due to their distributed nature. The synchronization of the actions of team members and the progressive integration of

Characteristics of VT as compared to FTFT	IT use in teams influences	…How?
High team diversity and low status differences	Selection processes	Common information bias is reduced in VT VT generate a higher number of alternatives in brainstorming activities
	Memory processes	The elaboration of task relevant information and memory interference are higher in VT
Lower levels of trust, team identity, cohesion, quality of communication and higher levels of conflict Lack of leadership and difficulties in developing procedural norms	Memory processes	In VT the knowledge integration is more difficult to achieve as compared with FTFT VT have difficulties in developing accurate transactive memory systems

Notes: VT = virtual teams; FTFT = face-to-face teams; IT = information technology

Table I.
The effects of communication technology on information processing

these actions is difficult to achieve because members are dispersed across organizational or national borders. It is a real challenge when teams are distributed across time zones too. In addition, the limited capacity of virtual communication tools to facilitate implicit coordination can have a negative effect on the integration of information in virtual teams.

Planning activities are also more difficult in virtual teams, and because planning has a strong effect on team effectiveness (Ilgen *et al.*, 2005), IT limits the information processing capabilities of virtual teams. The processes of structuring the task, allocating responsibilities, setting the goals and develop a strategy for achieving a common goal are difficult to accomplish in virtual teams. Even when the pool of knowledge and expertise is greater in a virtual team, the elaboration of task relevant information will be more limited, because of the process losses related to the virtual setting.

In virtual teams it is more difficult to develop interpersonal relationships because there is little or no face-to-face interaction. As a result, interpersonal relationships and trust and cohesion are not easy to create.

One of the most important sources of trust, especially in the first stages of team formation, is the quality of the (informal) interpersonal communication between the team members. The use of appropriate communication tools is crucial to let trust emerge. Since informal communication is less likely to occur in virtual teams and especially in global virtual teams, it is essential to use communication tools that facilitate this type of communication and have a high potential of transferring verbal as well as non-verbal information. This will ultimately lead to the development of strong interpersonal ties, which are essential for knowledge transfer and knowledge use within teams.

Theoretical implications

The model and integrative approach presented here adds in several ways to the study and knowledge of virtual teams. First, it provides a frame for research on the effectiveness of virtual teams in information processing tasks. Previous research was fragmented and divergent, tested theoretical propositions in different contexts and in

different types of virtual teams. The model presented can guide future research on virtual teams to focus on the interaction of the three subsystems that are essential for information processing: selection, memory and communication.

Second, virtual team effectiveness is discussed using a general model of information processing in teams, which is a parsimonious approach (Newell, 1990). This approach allows the use of already existing concepts and information processing mechanisms (e.g., accumulation, interaction, examination and accommodation) to describe the functioning of virtual teams in an integrated fashion. Moreover, this approach opens the possibility to perform simulation studies. Simulation methods are widely used – with exceptional results – in other applied domains including building industry, aviation and the space shuttle industry. Simulation allows studying the way in which a system functions in certain (sometimes critical) conditions (e.g., conditions that are either rare or difficult to manipulate in real life settings). The study of virtual teams will certainly benefit from this type of research. From a more pragmatic perspective, simulation experiments can be performed with less effort, fewer resources and less time than other studies with real virtual teams (Curşeu, 2006).

Third, the integrated model can be embedded in a larger context and an extended conglomerate of environmental variables, since it is inspired by an open system approach. This means that the model can easily incorporate a higher number of variables, linked to the way in which virtual teams process information.

Finally, the theoretical model introduces a number of variables related to information processing in teams (e.g., memory interference), which can be easily operationalized and investigated in empirical settings. A particularly interesting direction is to study the ways in which memory interference in virtual teams is influenced by the interaction between team diversity and communication media. Memory interference as well as the elaboration of task relevant information are certainly related to team diversity. To our knowledge there is no study addressing the effects of interaction between team diversity and status differences on team memory interference. The same is the case for the elaboration of task relevant information (see also Table I).

Managerial implications

From a managerial perspective, virtual teams have several pragmatic advantages above face-to-face teams. In addition, virtual teams allow group work across space (geographical) and/or time. Virtual teams can be composed of the best performing individuals in a particular field no matter how remote their location. In addition, there are other benefits, such as low costs, low travel efforts, and the enabling of flexible working practices.

Managing virtual teams is a challenge, however. Four important challenges, and the implications for management, will be further elaborated. First, in teams using IT, team processes are constrained, especially planning and coordination. This urges managers to set clear objectives for the team. Furthermore, structural feedback is needed to monitor activities and to ensure that the progress on the task and the team performance is transparent all the time. In the same vein, defining the roles is essential, since role ambiguity has a negative effect on the integration of information. On the other hand, however, it must be acknowledged that for certain tasks (especially complex cognitive tasks, such as new product development) the roles must be flexible because new tasks will emerge during the development process.

Second, the development of trust, cohesion and a strong team identity is one of the most difficult challenges for managers of virtual teams. Golden rules in this respect do not exist. Face-to-face interaction, however, can play an important role in this respect. Especially in the initial phases of the team project, meeting face-to-face will let the team members get acquainted with each other. Direct contact is essential for the development of trust and cohesion. A face-to-face meeting could also be used to set clear objectives for the team and discuss the coordination protocol. This protocol encompasses process rules and strategies that will be used to facilitate the attainment of the common goal.

Third, the difficulties in transactive memory and integration of information can be overcome by using opportunities for interaction frequently. By interaction the team members will develop a shared understanding of the task goals and the current state of accomplishment. Using the opportunities for monitoring and feedback will facilitate the development of the transactive memory of the virtual team to create a shared understanding of who knows what and who is doing what. Furthermore, the development of tools to evaluate the solutions or alternatives generated by the team members is crucial. As mentioned before, the evaluation of alternatives is one of the most relevant communication functions that influences decision quality. Virtual teams are disadvantaged compared to face-to-face teams in this respect. Virtual teams generally generate more alternatives. These teams often fail to evaluate the alternatives properly. This is why using evaluation tools might lead to a higher decision quality.

Finally, the task-technology principle concept is also important. When designing a virtual team an essential (initial) step is to decide upon the communication technology the team will use. The communication technology should be designed to enable optimal interactions between the team members, including access to task-relevant knowledge. The capabilities of the communication tools are also relevant because they should facilitate frequent interaction and enable the development of a shared understanding of the task. For the evaluation of alternatives and solutions, as well as monitoring and feedback functions, a coordination protocol should be implemented. Because the communication environment influences team effectiveness, it is essential to make sure that the virtual team members know how to use the communication tools.

Management of virtual teams requires task and process management. Effective leadership can help a virtual team to overcome the constraints imposed by the virtual character of the communication processes and information processing. Concerning the task, clear mission statements and realistic project team previews are extremely important to overcome the ambiguities inherent in the initial phases of team development (Furst *et al.*, 2004). Concerning team processes involving virtual teams in team building exercises will be beneficial for achieving a shared understanding of the task and mission, and help the team members to develop a shared sense of identity within the team. Because norms are difficult to develop in virtual teams, leaders should stimulate team members to develop norms that guide communication (such as timely information sharing, appropriated responses to electronic communication). This will also foster the development of trust in virtual teams (Jarvenpaa and Leidner, 1999). Team leaders should also set clear norms concerning timetables, deadlines and team members' obligations because structured schedules can have a positive impact on information integration, as well as on coordination across different time zones (Furst *et al.*, 2004). Because the use of technology can exacerbate conflict with negative influences on team outcomes, virtual teams' leaders should focus on identifying signs

of conflict as soon as they appear and deal with conflicts in a constructive way. In general, virtual teams have a great potential, and virtual team working has many advantages. However, without an effective leader, virtual teams may loose focus and the difficulties associated with the use of technology to communicate will outweigh the advantages of using virtual teams. Therefore, the way teams are managed makes a difference for their effectiveness in information processing!

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