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The Effect of IT and Co-location on Knowledge Dissemination

Michael Song, Hans Berends, Hans van der Bij, and Mathieu Weggeman

Due to the increasing globalization of businesses, new ideas for innovation need to be disseminated rapidly both within and across different departments and divisions. Frequently, ideas and information are dispersed over globally distributed organizations or team members. As a result, the exchange of knowledge has become not only very important for innovation but also highly complex. To facilitate this knowledge exchange, electronically mediated interactions are growing rapidly, replacing traditional face-to-face communications. However, literature provides contradicting results regarding the effectiveness of computer-mediated communication (CMC) versus face-to-face communication. This study attempts to reconcile differences in the literature on the benefits of CMC technologies and co-location. Focusing on knowledge dissemination in technology development processes in high-technology firms, the study investigates the relative impact of CMC technologies and co-location of research and development (R&D) staff, as well as the mutual interaction between them. The present article hypothesizes that CMC technologies and co-location of R&D staff have a positive impact on knowledge dissemination. Further, it is hypothesized that it is more favorable to co-locate R&D staff than to invest in CMC technologies and that the effects of co-location and CMC interact negatively. These hypotheses are tested using empirical data collected from 277 high-technology firms in the United States, and the results are generalized by conducting the same test on data from 125 high-technology firms in the Netherlands. Tests are conducted in a real-world setting, differing from previous comparative studies that mainly used laboratory experiments. Empirical results support the main effects of CMC technologies and co-location of R&D staff on knowledge dissemination. Other empirical results contradict conventional wisdom. Investing in CMC technologies is found to be favorable over co-locating R&D staff for knowledge dissemination. Moreover, the two communication channels strengthen each other. The discussion section presents the contours of a firm-level theory on communication infrastructures and knowledge dissemination, focusing on the scope and the heterogeneity of knowledge dissemination, which may explain these initially surprising results. From the arguments it follows that the choice for investment in co-location or CMC technologies depends on the scope of knowledge dissemination that has to be facilitated. Furthermore, the conclusion is made that effective knowledge dissemination requires a balanced investment in co-location and information technologies to be able to deal with the heterogeneous but interdependent types of knowledge dissemination.

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Introduction

Today, innovation requires the rapid sharing of knowledge within and across different functions and disciplines. The knowledge intensity of the product innovation process has led Nonaka (1994) to describe it as a knowledge creation process that thrives on the sharing of tacit and explicit knowledge. Madhavan and Grover (1998) explained innovation as the transformation of knowledge embedded in different places in an organization into knowledge embodied in a new product. Indeed, innovation management research has established time and again the positive association between innovation performance and the exchange of knowledge and information (Allen, 1977; Keller, 1994; Pelz and Andrews, 1966; Rothwell et al., 1974). This holds true for knowledge and information sharing both within research and development (R&D) and between R&D and other organizational functions, including marketing and manufacturing (Allen, Lee, and Tushman, 1980; Ancona and Caldwell, 1992; Clark and Fujimoto, 1991).

In the past, a primary strategy for ensuring a high level of knowledge dissemination was the co-location of R&D staff (Dyer and Song, 1997, 1998; Parry and Song, 1993; Song and Parry 1992, 1993a, 1993b; Song, Souder, and Dyer, 1997; Song, Xie, and Dyer, 2000; Xie, Song, and Stringfellow, 1998, 2003). For example, Philips Electronics has long relied on physical proximity to stimulate technological knowledge sharing. In 1923, the research organization moved into a new laboratory that was designed to foster spontaneous contacts between researchers (Boersma, 2002, p. 44). And a few years ago, Philips initiated the development of a high-tech campus that by 2008 is intended to co-locate about 8,000 Philips researchers, developers, and engineers, as well as other high-tech firms and start-ups. The principal motive for this physical concentration of innovation activities is to increase the sharing of knowledge and other resources. Indeed, Philips Research has a rich and extensive track record of knowledge sharing (Boersma, 2002; Berends et al., 2006). Evidence of the success of the high-tech campus can be read from the range of other companies locating their R&D activities there.

Nevertheless, the innovation activities of many companies are becoming increasingly dispersed as they follow the trend to internationalize their R&D activities. The impetus behind this trend is to bring R&D closer to foreign markets, to make better use of local knowledge pools and networks, and to reduce personnel costs. Moreover, dispersion of R&D activities can be a result of the acquisition of foreign companies with own R&D facilities (Gassman and Von Zedtwitz, 1998). Such dispersion of R&D activities complicates the organization-wide dissemination of knowledge required for successful innovation. Many companies are using information and communication technology (ICT) to replace or in addition to co-location and face-to-face contact (De Meyer, 1991; Hameri and Nihtilä, 1997; Howells, 1995; Malhotra et al., 2001; Sethi, Pant, and Sethi, 2003). Philips, for example, has invested in state-of-the-art ICT facilities at its high-tech campus. But can ICT enable the required patterns of knowledge dissemination? To enhance knowledge dissemination in innovation, should companies invest in co-location? In ICT? Or in both?

The current literature offers no conclusive answers to these questions. It shows that though companies invest heavily in information technology (IT), the value of doing so is a matter of debate (e.g., Brynjolfsson, 1993). A number of case studies document the successful use of ICT in innovation projects (Boutellier et al., 1998; Hameri and Nihtilä, 1997; Malhotra et al., 2001). For instance, Malhotra et al. (2001) describe the development of a radically improved rocket engine by a virtual team of Boeing-Rocketdyne who relied almost entirely on the use of computer-mediated communication (CMC) technologies. But others (e.g., Cooper, 2003) enumerate the various limitations of CMC systems for innovation practices. Even the effect of co-location is not as evident as is often suggested. Allen (1977) and Kraut, Egido, and Galegher (1990) found that the probability of communication between individuals decreases as distance increases. McDonough, Kahn, and Barczak (2001) supported this result at the level of new product development (NPD) teams. However, Moenaert and Caeldries (1996) found no significant relationship between proximity and technological communication on the departmental level, and Rafii (1995) believed that the value of co-location may be greatly exaggerated. No study to date has systematically compared the effectiveness of co-location and IT for knowledge dissemination in real-world innovation practices.

Co-location has been compared to the use of IT in experimental research. Much of this research suggests that groups using electronic communication systems communicate less effectively in many circumstances than do groups meeting face to face. For instance, Hightower and Sayeed (1995, 1996) found that virtual teams exchange information less effectively than face-to-face groups. However, the results of other studies (e.g., Bordia, 1997; Warkentin, Sayeed, and Hightower, 1997) are not nearly so conclusive. More importantly, these experimental studies have significant methodological limitations: They use small, ad hoc groups of M.B.A. students and avoid sustained, project-oriented teamwork of the sort that is important in most real-world organizations; the tasks to be executed by the ad hoc groups are relatively small and simple compared to the development of new technologies and new products for the global market; and evaluation of the experiments takes place at the group level instead of at the organizational level (e.g., Hightower and Sayeed, 1995, 1996; Warkentin, Sayeed, and Hightower, 1997).

The present study seeks to overcome the contradictory results, unanswered questions, and methodological limitations that characterize previous research on the value of co-location and CMC technologies for knowledge dissemination. The study empirically examines the question of whether it is more favorable for a strategic business unit to co-locate R&D staff or to invest in CMC technologies. The dependent variable is knowledge dissemination within technology development. Technology development is one of the most important stages of the NPD process. For example, Song and Parry (1997a, 1997b) and Song and Montoya-Weiss (1998, 2001) explicitly model NPD as a five-stage process, of which one process is technology development (see also Song and Parry, 1999). Technology development sometimes partly precedes actual NPD projects. It provides the technological foundation for the successful development of a new product or a range of new products (Ajamian and Koen, 2002; Nuese, 1995). The degree to which uncertainties and ambiguities associated with technology development have been addressed strongly impacts the feasibility of well-structured NPD projects (Ajamian and Koen, 2002). The present study focuses specifically on the dissemination of technological knowledge within the technology development process, as measured at the strategic business unit (SBU) level.

Following Nonaka (1994) and the epistemological tradition (Audi, 1995), *knowledge* is defined here as justified true belief. Formally, knowledge here refers to information that has entered human belief systems and has been validated by experience. *Knowledge dissemination* is defined as the process and extent of technological information exchange within a given organization. The exchange of information can occur both formally and informally and both horizontally (i.e., interdepartmentally) and vertically within the organization (Van der Bij, Song, and Weggeman, 2003). Knowledge dissemination contributes to technology development in several ways. Knowledge sharing yields ideas for new technologies and new products (Langrish et al., 1972), yields evidence required for the evaluation of concepts (Allen, 1977), reduces risks (Cooper, 2003), creates shared understanding required for collaborative development (Hoopes and Postrel, 1999), and enables people to keep track of such things as competitors' development efforts.

Researchers usually classify information technologies according to their technological functions (Kendall, 1997). Huber (1990) included computer-assisted communication technologies and computer-assisted decision-aiding technologies (e.g., decision support systems, expert systems) in his definition of advanced information technologies. The present study concentrates on computer-assisted communication technologies, also known as *computer-mediated communication* (CMC) *technologies*, which are defined here as information technologies that enable, intensify, or expand the interactions of multiple agents (e.g., organizational members, departments) in the execution of a planning, design, decision, or implementation task. Many CMC technologies are currently being used in new technology and product development: e-mail, content management systems, groupware (e.g., collaborative notebooks, forums, electronic whiteboards), Web pages, file transfer systems, and videoconferencing (Boutellier et al., 1998; Howells, 1995; Malhotra et al., 2001; Sethi, Pant, and Sethi, 2003). Finally, *co-location* of R&D staff is defined as the positioning of departments and offices of R&D personnel in close proximity to each other (Pinto, Pinto, and Prescott, 1993; Xie, Song, and Stringfellow 1998, 2003).

This article is organized as follows. First, it presents a conceptual framework and the underlying theory on the subjects of co-location and computer-mediated communication. Then the research hypotheses are presented. Subsequently, the article describes the research design and presents the analysis and results. First, results from the United States and afterward results from the Netherlands are presented. The last section offers conclusions and implications and discusses limitations and directions for future research.

Theoretical Background and Hypotheses

The conceptual framework for this study, which is presented in Figure 1, focuses on the impact of CMC

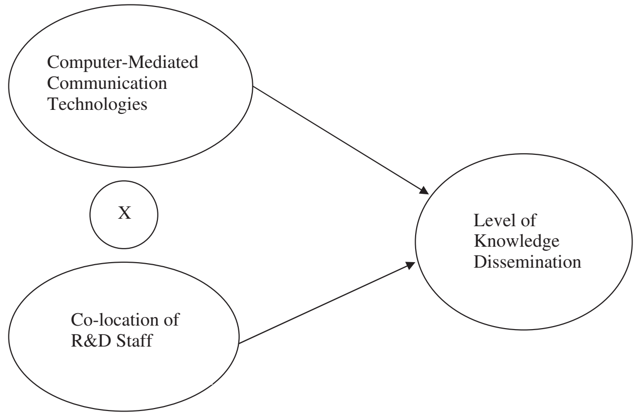

Figure 1. A conceptual framework for studying the effects of computer-mediated communication technologies and co-location of R&D staff, as well as their mutual interaction on the level of knowledge dissemination

technologies and co-location on the level of knowledge dissemination in technology development. Briefly, the framework suggests that, besides positive main effects of CMC technologies and co-location of R&D staff on the level of knowledge dissemination, there is an interaction effect. In the theoretical discussion that follows, these claims are elaborated and testable hypotheses are deduced. The focus is especially on the comparison of co-location and CMC technologies and the joined interaction effect of these communication infrastructures on knowledge dissemination in technology development.

To develop hypotheses on the suitability of co-location and CMC technologies for the dissemination of technological knowledge, the differences between co-location and CMC technologies that make a difference for knowledge dissemination must be articulated. Relevant theory, found in the fields of innovation management, communication studies, and organization science, suggests that five major differences between co-location and CMC technologies influence their ability to disseminate knowledge: (1) media richness; (2) the facilitation of relationship building; (3) the ability to disseminate tacit knowledge; (4) the spontaneity of encounters; and (5) the ability to overcome time and space constraints. The first four differences essentially favor co-location, whereas the last one favors CMC technologies.

First, technology development calls for both reduction of uncertainty and resolution of equivocality. Uncertainty refers to a lack of objective information. Equivocality is synonymous with ambiguity and refers to the existence of ill-defined problems, poor understanding, conflicting interpretations, and confusion. Particularly in the early phases of technology development, ambiguity is high (Ajamian and Koen, 2002; Garud and Van de Ven, 1992). In media richness theory, the richness of a communication medium determines its ability to reduce uncertainty and to resolve equivocality. Daft and Lengel (1984, 1986) define the concept of media richness as the ability to change understanding within a specified time interval. The richness of a medium is based on four underlying dimensions: (1) the availability of feedback mechanisms, for example, to test mutual understanding; (2) the availability of multiple cues, including verbal, paraverbal (tone of voice, inflection, voice volume), and nonverbal (body language) cues; (3) the language variety, including the breadth of vocabulary, that is supported; and (4) a personal focus (Daft, Lengel, and Trevino, 1987). Based on these dimensions, communication media can be ordered along a spectrum from rich (e.g., a face-to-face meeting) to lean (e.g., a written report). Rich media are hypothesized to have a strong impact on equivocality resolution. Conversely, lean media are strong in uncertainty reduction. Though media richness theorists disagree on the richness of particular electronic media, CMC technologies are generally regarded as being less rich, suggesting that their capacity to support information exchange under ambiguity is weak. Indeed, Boutellier et al. (1998, p. 16) described how IBM relied on e-mail communication in a development project, but only after shared understanding was developed in co-located discussions.

Second, the richness of a communication medium influences the capacity to build relationships. Short, Williams, and Christie (1976) introduced the notion of social presence, that is, the feeling that others are involved in a communication exchange, and argued that it is determined by the communication medium: The fewer channels or cues that are available within a medium, the less attention is paid by the user to the presence of other social participants. Consequently, computer-mediated communication is low in social presence compared to face-to-face communication (Chidambaram and Jones, 1993; Walther, 1995). Warkentin, Sayeed, and Hightower (1997) found that groups meeting face to face build stronger relational links. Similarly, Handy (1995) stressed that face-to-face meetings are important for building trust among organization members. This has strong implications for knowledge dissemination because it has repeatedly been found in field studies that trust and other relational characteristics are important enablers of knowledge sharing in organizations (e.g., Blau, 1963; Edmondson, 1999; Szulanski, 1996).

The third difference between co-location and CMC technologies of relevance to knowledge dissemination in technology development is the ability to disseminate tacit knowledge. Face-to-face communication and computer-mediated communication differ in the degree to which they enable the dissemination of situated and tacit knowledge (Pedersen, Petersen, and Sharma, 2003). Experimental studies comparing face-to-face and computer-mediated communication typically use fictional tasks such as solving a murder mystery (Warkentin, Sayeed, and Hightower, 1997) or selecting a job candidate (Hightower and Sayeed, 1996) that require the combination of relatively simple pieces of explicit information. However, a substantial part of technological knowledge and expertise is tacit, that is, difficult to verbalize (Polanyi, 1958), and situated, meaning it is interconnected with a particular physical and social context (Lave and Wenger, 1991; Von Hippel, 1994). The dissemination of tacit and situated technological knowledge is enabled by intensive interaction and the joint observation and operation of material artifacts (Brown and Duguid, 2001; Hansen, 1999; Tyre and Von Hippel, 1997). R&D staff members often communicate with their materials, samples, instruments, prototypes, products, and machines at hand to illustrate or support what they want to convey or to show what they cannot verbalize. Moreover, these material artifacts are often touched, handled, and demonstrated as a way to disseminate knowledge about them or the skill to use them (Nonaka, 1994; Pinch, Collins, and Carbone, 1996). Thus, in addition to supporting a wide range of verbal, paraverbal, and nonverbal cues, co-location enables communication partners to have access to the same observational cues and to engage in the same practice, thereby enhancing the dissemination of tacit and situated knowledge.

Fourth, the value of co-location is not only that it offers high-quality face-to-face communication but also that it requires little effort to initiate communication in a co-located situation (Kraut, Egido, and Galegher, 1990). Gerstberger and Allen (1968) discovered that not perceived quality, but instead ease of use, guides the selection of information channels and sources by researchers and engineers. Co-location increases the amount of communication that occurs since it reduces the effort required to make intentional visits and increases the chance that staff members will encounter each other unexpectedly and engage in unplanned, spontaneous exchanges in the corridor or the coffee corner (Allen, 1977; Kraut, Egido, and Galegher, 1990). The corridors, lunchrooms, and other facilities at the high-tech campus developed by Philips have been designed specifically to foster such unexpected meetings. This effect is hard to realize in computer-mediated communication.

Finally, the fifth difference between co-location and CMC technologies relevant to technology development is that many CMC technologies have the capacity to overcome time and space constraints (Constant, Sproull, and Kiesler, 1996; Warkentin, Sayeed, and Hightower, 1997). Asynchronous communication technologies are not hindered by differing time zones. The use of e-mail offers members of large international corporations the convenience of communicating with a larger number of staff using one message than would be possible by face-to-face communication. A further advantage of CMC technologies is that they almost always come equipped with a memory function and hence facilitate the retention of and later retrieval of knowledge. Malhotra et al. (2001) described how the use of a shared virtual notebook enabled the developers of a new rocket engine to capture, track, and reuse information. This memory function can be especially valuable in the medium to long term because knowledge from one innovation project can be used years later in another project (Garud and Nayyar, 1994).

What implications do these differences between co-location and CMC technologies have for knowledge dissemination in technology development? CMC technologies are clearly better suited for the transfer of explicit knowledge and unambiguous information and for knowledge dissemination across time and space. These arguments suggest that CMC technologies facilitate at least some of the knowledge dissemination that is required for successful technology and product development. Indeed, a number of case studies have documented successful virtual collaboration in NPD projects (Boutellier et al., 1998; Hameri and Nihtilä, 1997; Malhotra et al., 2001). Therefore, it is hypothesized that

H1: The use of computer-mediated communication technologies is positively associated with the level of knowledge dissemination in technology development.

Several empirical studies document the appropriateness of co-location for knowledge dissemination (Allen, 1977; Kraut, Egido, and Galegher, 1990; McDonough, Kahn, and Barczak, 2001). According to the literature just reviewed, co-location is particularly valuable for disseminating information under conditions of ambiguity, for disseminating tacit knowledge, and for developing relationships. Moreover, spontaneous encounters may stimulate knowledge dissemination in a co-located situation. Therefore, it is hypothesized that

H2: Co-location of R&D staff is positively associated with the level of knowledge dissemination in technology development.

The third hypothesis concerns the relative strength of the effects of CMC technologies and co-location. A majority of the theoretical arguments presented already favors co-location over CMC technologies. Whereas CMC is weak in dealing with ambiguous information, face-to-face communication can reduce both ambiguity and uncertainty. CMC is capable of transferring explicit knowledge, whereas face-to-face communication enables the transfer of tacit and situated knowledge as well. Furthermore, face-to-face communication promotes relationship building to a much greater degree than does CMC. Finally, co-location allows for the possibility of unplanned and accidental encounters. These differences can be critical when considering that real-world technology and product development are complex tasks involving multiple ambiguities and requiring the exchange of tacit and situated knowledge as well as unpredictable interaction among people who have developed long-standing relationships. Most experimental studies have found that co-located groups disseminate more knowledge than groups using CMC technologies (e.g., Hightower and Sayeed, 1995, 1996). Finally, plain old common sense tells us that co-location is better for knowledge dissemination than computer-mediated communication. Therefore, it is hypothesized that

H3: Co-location of R&D staff is more positively associated with the level of knowledge dissemination in technology development than computer-mediated communication technologies.

The final claim represented in the conceptual model is that interaction occurs between the effects of CMC technologies and co-location. That is, the effects of CMC technologies and co-location depend on the other's presence. Assuming the factors CMC technologies and co-location of R&D staff are not mutually independent, the question is whether they strengthen or weaken each other—that is, whether the interaction is positive or negative.

The existing literature provides grounds to assume that CMC technologies and co-location weaken each other, meaning that they have a negative mutual interaction. A basic reason to assume this is that they both provide access to communication channels. When one type of communication channel is already present, the benefits of adding another type of communication channel are smaller than they would be if the first was not present. For example, Chidambaram and Jones (1993) found in an experimental study that the addition of an electronic meeting system improves the perception of communication effectiveness for dispersed groups but not for co-located groups. They stated that "there is little doubt, as the results of this study and others indicate, that face-to-face meetings offer the most natural interface for group communication. Introduction of any artifact, like electronic communication support, only serves to reduce the inherent 'naturalness' of this medium" (p. 480). Hansen, Nohria, and Tierney (1999) made an even stronger point in their knowledge management theory, asserting that organizations should choose between a codification strategy (e.g., focusing on CMC technologies) and a personalization strategy (e.g., focusing on face-to-face communication). Effective investment typically should be made according to an 80:20 rule and not by an even distribution, since the two knowledge-management strategies call for different settings. When standardized, mature products are produced and staff relies on explicit knowledge to solve problems, a codification strategy may be most effective, whereas producing customized, innovative products and solving problems using tacit knowledge demands for a personalization strategy.

Thus, it can be expected that when the co-location of R&D staff is relatively high, the impact of enhancing CMC technologies on knowledge dissemination is smaller than when co-location is low. For example, when an organization member wants to communicate with a colleague, it is more important to have access to e-mail when this person is dislocated than when the colleague has an office next door. Correspondingly, it can be expected that when the use of CMC technologies is relatively high, the impact of enhancing co-location on knowledge dissemination is smaller than when the use of CMC technologies is relatively low. Summarizing, it is hypothesized that

H4a: There will be a joined interaction effect between the use of computer-mediated communication technologies and co-location of R&D staff on the level of knowledge dissemination in technology development.

H4b: The interaction effect will be negative, meaning that the use of computer-mediated communication technologies and co-location of R&D staff weaken each other.

Methodology

Research Instrument Development Procedure

Existing scales are used for the use of CMC technologies and the co-location of R&D staff. For the level of knowledge dissemination, six steps were undertaken to develop a new scale.

First, a literature review was conducted to identify a pool of items for the level of knowledge dissemination. Items were generated that tap the domain of the construct as closely as possible (Churchill, 1979).

Second, in-depth interviews were conducted to determine whether the defined construct can be understood (i.e., face validity) and whether the accompanying scale items are clear and complete. This field research was conducted in seven knowledge-intensive organizations: IBM, Intel, Merck, Microsoft, Motorola, Philips, and Sony. A total of 22 senior executives, IT officers, and R&D experts were interviewed during this research step. The interviews followed a standard protocol and consisted of two parts. Part one was designed to elicit and define salient scale items for the construct. Part two addressed perceptions of the relevance and completeness of the construct and scale items drawn from the literature review and the earlier in-depth interviews.

Third, a content analysis was performed using the procedure recommended by Kassarjian (1977). The objective of this analysis was to standardize the outcomes of the interviews from the field research. All measurement items generated from the preceding two steps were assigned a unique code. Five researchers with adequate knowledge in the field of knowledge management independently verified how each item could be positioned within the developed research instrument. Four researchers compared their outcomes and discussed any differences. Where consensus could not be reached, the fifth researcher served as a referee and determined the final positioning.

Fourth, using the measurement items generated, the first draft of the research instrument was developed and then discussed with a representative panel of experienced IT officers and R&D managers. These discussions helped to refine a number of the items included in the first draft of the research instrument. Following the recommendations of Churchill (1979), subsets of unique items that possessed different shades of meaning among the informants were identified. A list of constructs and corresponding measurement items was submitted to a panel of academic experts for critical evaluation and suggestions. A questionnaire was constructed based on items judged to have high consistency and face validity.

Fifth, the survey—including the scales for CMC technologies and co-location of R&D staff—was pretested for clarity and appropriateness using the participants of the field research. The participants were asked to identify any ambiguity and to indicate any difficulties they experienced in responding to the items. Based on the feedback obtained from the participants, some items were eliminated, and others were modified.

Sixth, the final research instrument was subjected to additional pretesting that involved personal interviews with six executives at Motorola, Microsoft, and IBM, who were asked to complete the survey as it applied to their business unit. At this stage, the pretest resulted in only minor refinement of two measurement items.

Measures

The constructs, accompanying scale items, and construct reliabilities are listed in the Appendix.

Dependent variable. The scale for the level of knowledge dissemination was developed using the research instrument development procedure explained earlier (Van der Bij, Song, and Weggeman, 2003). Knowledge dissemination, as defined previously, is the process and extent of technological information exchange within a given organization. Several managers noted that for an organization to be competitive in a knowledge-intensive economy, it must communicate and disseminate knowledge to relevant departments and individuals, whether by informal hallway talk or by more formal media. Moreover, they claim that doing fundamental research is highly competitive, but only when new ideas are communicated at high speed throughout the organization. R&D directors and marketing managers at both Philips and Sony develop procedures for periodically circulating documents (e.g., reports, newsletters) that describe newly created knowledge and the progress of technology development activities. Finally, most managers acknowledged that communication between R&D and marketing could be improved. Therefore, a six-item scale was developed, measuring (1) the extent of knowledge sharing and dissemination in the organization, (2) the extent to which data on technology development are regularly disseminated in all levels of the company, (3) the extent that information about successful and unsuccessful technology development is communicated freely across all business functions, (4) the amount of cross-functional communication in the company concerning technology developments, (5) the amount of informal hall talk concerning technology development tactics or strategies, and (6) the regularity with which the company circulates documents (e.g., reports, newsletters) that describe newly created knowledge.

Independent variables. Based on the field research conducted at IBM, Intel, Merck, Microsoft, Motorola, Philips, and Sony, the description of computer-mediated communication technologies *(IT_c)* by Sethi and King (1994) was validated and adopted:

> Computer-mediated communication technologies are information technologies that provide ways to enable, intensify, or expand the interactions of multiple agents (e.g., organizational members, departments) in the execution of a planning, design, decisions, or implementation task. There are several possible uses of the IT_c: (1) to help reduce geographical or time constraints; (2) to enforce rules, policies, or priorities over development activities and resources; and (3) to improve the sharing and exchange of information across all levels of the organization or intra organizations. Examples of the IT_c are group support systems (GSS), executive information systems (EIS), e-mail, video conferencing systems, web-based conferencing, and electronic data interchange (EDI).

This description was distributed among the participating companies, and they were then asked to provide data for the following dimensions regarding the IT_c systems: (1) the level of the investment in the IT_c

relative to the industry norm or standard (rated on an 11-point scale in which 0 = much lower than the industry norm or standard and 10 = much higher than the industry norm or standard); (2) the level of availability of the IT_c systems (rated on an 11-point scale in which 0 = available to only a few people and 10 = available to everyone); (3) the level of state-of-the-art technology in the IT_c systems (rated on an 11-point scale in which 0 = much lower than the industry norm/standard and 10 = much higher than the industry norm/standard); (4) The level of easiness to use the IT_c systems (rated on an 11-point scale in which 0 = very difficult to use and 10 = very easy to use); (5) The response time of the service of the IT_c systems (rated on an 11-point scale in which 0 = a long response time and 10 = a short response time); (6) The reliability of the service of the IT_c systems (rated on an 11-point scale in which 0 = low reliability and 10 = high reliability); (7) The dependability of the service of the IT_c systems (on an 11-point scale in which 0 = not dependable and 10 = highly dependable). This seven-item scale was adopted from Sethi and King (1994).

Co-location of R&D staff is defined as the proximity of different departments and offices of R&D personnel to each other. The definition and four-item scale are adopted from Pinto, Pinto, and Prescott (1993). Specific measures are the following: (1) The physical distance between the different R&D departments is (0 = none; 10 = very far; reversed item); (2) The offices of R&D personnel are located in close proximity to each other (rated on an 11-point scale in which 0 = strongly disagree and 10 = strongly agree); (3) It is easy for the R&D personnel to travel to meet (rated on an 11-point scale in which 0 = strongly disagree and 10 = strongly agree); and (4) R&D personnel often have problems to communicate with each other due to the physical separation of their offices (rated on an 11-point scale in which 0 = strongly disagree and 10 = strongly agree; reversed item).

Data-Collection Procedures

For study 1, the data were collected from 277 high-tech firms in the United States; the sampling frame consisted of the companies listed in the *High-Technology Industries Directory*. The total design method recommended by Dillman (1978) was used for data collection. After making initial contact to identify appropriate informants, the original list was narrowed to 686 firms for which valid contact information for the final survey had been obtained. Phone calls were made to verify the accuracy of the contact information.

Two questionnaires were developed and data were collected from two key informants of each firm: an SBU manager and a senior manager outside the SBU. The field research interviews suggested that senior managers at the corporate level are qualified to provide data pertaining to the level of knowledge dissemination. SBU managers are generally viewed as qualified informants for the SBU's operations and were therefore asked to respond to the items on co-location and IT. To minimize potential common-method bias, data for measuring the independent variables and the dependent variable were collected from different sources.

The first mailing packet included a personalized letter, an express-mail postage-paid envelope with an individually typed return-address label, and questionnaires. Three follow-up letters were sent. The questionnaire, together with a reminder letter, was resent to each firm that did not respond within three weeks. The questionnaire was also resent with a second reminder letter. To increase the response rate, extensive personal contacts and networking efforts were supplemented with numerous incentives. Complete data were collected from 277 of the original 686 firms (a 40% response rate) operating in telecommunications equipment; semiconductors and computer-related products; software-related products; Internet-related services and equipment; instruments and related products; electronic and electrical equipment; pharmaceuticals, drugs, and medicines; and industrial machinery and equipment.

To test for possible nonresponse bias, early responses (i.e., those received following the first wave of mailing) were compared with late responses on the level of knowledge dissemination of the firm. The results indicated no significant differences at a 95% confidence interval. Additional financial data from secondary sources (e.g., CompuStat) and company annual reports also were collected to compare respondent and nonrespondent firms in terms of their annual sales and number of employees. The results indicated that no significant differences between the responding and nonresponding firms at a 95% confidence interval. Thus, it was concluded that there is no nonresponse bias and that the results may be generalized to the firms that did not respond.

Analysis and Results

A two-way analysis of variance (ANOVA) test was conducted by the general linear model (GLM) procedure in the SAS program to test the hypotheses formulated earlier. The two factors manipulated were CMC technologies and co-location of R&D staff. Both factors have two levels: high and low. SBUs are assumed to have a low level of CMC technologies, or co-location of R&D staff, if the level of the CMC technologies or the co-location of R&D staff is beneath the mean of the particular variable in the survey. Means and standard deviations of the studied variables are presented in Table 1a. Results of the Duncan mean difference test (alpha = 0.05) show no significant difference between the means in cells (1,1) and (1,2). However, a significant difference is shown between these cells and cells (2,1) and (2,2) as well as between the cells (2,1) and (2,2). Results of the two-way ANOVA are shown in Table 2a. The findings confirm H1, H2, and H4a. H3 and H4b cannot be confirmed.

As predicted by H1, there is a main positive effect of CMC technologies on the level of knowledge dissemination ($p < .0001$). Therefore, when R&D management invests in CMC technologies, it may be favorable for the level of knowledge dissemination.

A main positive effect of co-location of R&D staff on the level of knowledge dissemination is also found ($p < .0001$). Thus, H2 is confirmed, which means that it is worthwhile for R&D management to co-locate R&D staff to achieve a higher level of knowledge dissemination.

H3 concerns the relative impact of CMC technologies and co-location of R&D staff on the level of knowledge dissemination. Table 1a shows that CMC technologies have a stronger impact on the level of knowledge dissemination than does the co-location of R&D staff. It also follows from the Duncan mean difference test (alpha = 0.05) that for a low level of CMC technologies the transition from dispersion

Table 1a. Means and Standard Deviations of the Studied Variables: Results from Study 1, U.S. Firms[a]

Computer-Mediated Communication Technologies	Co-location of R&D Staff: Dispersed	Co-located	Grand Means
	Level of Knowledge Dissemination		
Low Level	3.83 (1.70) $N = 87$	4.13 (2.09) $N = 53$	3.94 (1.86) $N = 140$
High Level	5.40 (1.78) $N = 40$	6.68 (1.59) $N = 97$	6.31 (1.74) $N = 137$
Grand Means	4.32 (1.87) $N = 127$	5.78 (2.15) $N = 150$	

[a] Numbers in parentheses are standard deviations.

Table 1b. Means and Standard Deviations of the Studied Variables: Results from Study 2, Dutch Firms[a]

Computer-Mediated Communication Technologies	Co-location of R&D Staff: Dispersed	Co-located	Grand Means
	Level of Knowledge Dissemination		
Low Level	5.52 (1.29) $N = 30$	5.33 (1.65) $N = 24$	5.44 (1.45) $N = 54$
High Level	5.93 (1.60) $N = 28$	6.67 (1.18) $N = 43$	6.38 (1.40) $N = 71$
Grand Means	5.72 (1.45) $N = 58$	6.19 (1.50) $N = 67$	

[a] Numbers in parentheses are standard deviations.

Table 2a. Results from Two-Way ANOVA, the Level of Knowledge Dissemination as a Dependent Variable: Results from Study 1, U.S. Firms

Source of Variation	Sum of Squares	DF	F	Significance of F
	Level of Knowledge Dissemination			
CMC Technologies	276.05	1	89.54	< .0001
Co-location of R&D Staff	145.54	1	47.21	< .0001
Co-location × CMC Technologies	14.33	1	4.65	.0320

Table 2b. Results from Two-Way ANOVA, the Level of Knowledge Dissemination as a Dependent Variable: Results from Study 2, Dutch Firms

Source of Variation	Sum of Squares	DF	F	Significance of F
	Level of Knowledge Dissemination			
CMC Technologies	22.21	1	12.03	.0007
Co-location of R&D Staff	12.28	1	3.60	.0601
Co-location × CMC Technologies	7.98	1	3.26	.0733

to co-location of the R&D staff has no significant impact, whereas all other transitions have a significant impact. Therefore, H3 cannot be confirmed. This interesting result, contradicting as it does the mainstream literature, is discussed following.

In H4a, a joined interaction effect is claimed of CMC technologies and co-location of R&D staff on the level of knowledge dissemination. Table 2a shows an ordinal interaction effect ($p = .0320$), thus confirming H4a.

To examine the nature of the interaction between CMC technologies and co-location of R&D personnel, the concepts of supermodularity and complementarity of Milgrom and Roberts (1990, 1995) are adopted. In short, the knowledge dissemination function is supermodular when the sum of the changes in the function when the two infrastructure characteristics are strengthened separately is less than the change resulting from the strengthening of both infrastructure characteristics together. In such a case, both infrastructure characteristics are described as being complementary.

In a formal notation, this can be expressed as follows. Let i denote the level of co-location of R&D personnel, then $i = 0$ when the level of co-location is relatively low and $i = 1$ when the level of co-location is relatively high. Let j denote the level of CMC technologies, then $j = 0$ when this level is relatively low and $j = 1$ when this level is relatively high. Let $x = (i,j)$ denote a level of R&D co-location and of CMC technologies, then

$$x \in T = \{(i,j)|I = 0,1; \ \ j = 0,1\}.$$

Let $\max(x, x')$ be the point in T whose k^{th} component is $\max(x_k, x'_k)$ and let $\min(x, x')$ be the point in T whose k^{th} component is $\min(x_k, x'_k)$. The knowledge dissemination function F: $T \to R$ is defined to be supermodular if for all x and x' in T,

$$F(x) + F(x') \leq F(\min(x, x')) + F(\max(x, x')). \quad (1)$$

A function F is called submodular if $-F$ is supermodular. It can easily be shown that Equation (1) is the same as

$$[F(x) - F(\min(x, x'))] + [F(x') - F(\min(x, x'))] \leq F(\max(x, x')) - F(\min(x, x')). \quad (2)$$

Moreover, it can easily be shown that a function is supermodular if and only if the interaction effect is significantly positive. From Table 1a it is clear that Equation (2) holds. Therefore, H4b cannot be confirmed. The level of knowledge dissemination is supermodular with respect to R&D co-location and CMC technologies; thus, both factors are complementary.

Results of Study 2: Testing the Generalizability of the Results from Study 1

To increase the generalizability of these unexpected and interesting results, a study was undertaken of high-technology firms in the Netherlands. The protocol developed for the U.S. study was again used to collect data from 125 companies based in the Netherlands. Participating companies operated the same types of businesses as those participating from the United States. Means and standard deviations of the variables studied in the Dutch database are presented in Table 1b.

Results of the Duncan mean difference test (alpha = 0.05) show no significant difference in the Dutch database between the means in cells (1,1), (1,2), and (2,1), which, however, are significantly smaller than the mean in cell (2,2). Results of the two-way ANOVA are presented in Table 2b.

Table 2b shows that the results of the Dutch study are less clear-cut than those from the U.S. study. Nevertheless, the positive main effects of CMC technologies ($p = .0007$) and co-location of R&D staff ($p = .0601$) on the level of knowledge dissemination are evident if alpha is changed to .10. Therefore, H1 and H2 are confirmed. Table 1b shows that the impact of CMC technologies on the level of knowledge dissemination is stronger than the impact of co-location of R&D staff, although the differences are not significant. These results do not confirm H3. Table 2b shows a joined interaction effect of computer-assisted technologies and co-location on the level of knowledge dissemination ($p = .0733$); therefore, H4a is confirmed. H4b, concerning submodularity of CMC technologies and co-location, is not confirmed in the Netherlands sample (Table 1b) since calculations show a complementary effect of the two factors. This means that the two factors strengthen each other, as was also found in the U.S. data.

Discussion and Future Research Directions

Previous research on the management of innovation established the insight that innovation processes in technology-intensive industries are enabled and enhanced by knowledge dissemination, both within R&D and between R&D and other organizational functions such as marketing and manufacturing. Traditionally, companies have relied on the co-location of staff as a means of stimulating knowledge sharing. However, the globalization of business in general and R&D in particular has turned co-location into a luxury that is not always within reach (Hameri and Nihtilä, 1997) and raised the question of whether knowledge dissemination also can be facilitated by information technology.

In this study, four hypotheses concerning the impact of CMC technologies and co-location of R&D staff on the level of knowledge dissemination in technology development were developed and tested. Besides main effects, an interaction and a non-complementarity effect of CMC technologies and co-location of R&D staff, as well as their relative impact, were hypothesized and tested. Deviating from existing studies, the hypotheses were tested empirically in a real-world setting—that is, the complex new technology development process of a strategic business unit of a high-technology firm. Initially, tests were conducted only in the United States. For the purpose of generalization, additional tests were later conducted in the Netherlands, and the results were roughly the same. In short, positive main effects of CMC technologies and co-location of R&D staff were found.

Thus, this research has confirmed the established belief in co-location as an enabler of knowledge dissemination in innovation (e.g., Allen, 1977). Yet it has also confirmed the conclusions of case studies that document the successful use of IT for knowledge dissemination in innovation products (Boutellier et al., 1998; Hameri and Nihtilä, 1997; Malhotra et al., 2001).

The most interesting results and, in the present authors' view, the most valuable contributions of this study are the high impact of CMC technologies on the level of knowledge dissemination compared to the co-location of R&D staff and the complementarity of these two factors. Though most media richness and CMC theories, as well as general communication, innovation, and knowledge management studies, favor co-location over computer support, this study shows the contrary. Moreover, though Hansen, Nohria, and Tierney (1999) argued that companies must choose either face-to-face communication or IT as a knowledge management strategy and Chidambaram and Jones's (1993) study offers some empirical evidence for that, the present study shows that they interact and strengthen each other. An explanation for these unexpected results may be that the effects of CMC technologies and co-location were studied at the firm level, but the theories underlying the hypotheses focus at the dyadic level or the group level. To understand these surprising results, a firm-level perspective is needed. In the remainder of this discussion some firm-level considerations are suggested and implications for the management of innovation are drawn.

Knowledge dissemination at an organizational level differs both in scope and in the heterogeneity of its characteristics from knowledge dissemination at a group level. The scope of knowledge dissemination within a multinational industrial firm involves more people, on the scale of several thousands. The larger scope of knowledge dissemination at the firm level may explain the stronger impact of CMC technologies, which seem better able than co-location to deal with a larger scope. Knowledge dissemination by co-location cannot be extended with impunity. Allen's (1977) demonstration of a strong positive effect of physical proximity on communication frequency concerned dyads. This does not imply that the same holds at the level of the firm. Increasing knowledge dissemination within one dyad (person A and person B) by reducing distance may decrease knowledge dissemination within another dyad (person B and person C) by increasing distance between them. In the reality of globalized business, co-location of R&D staff might lead to the separation of R&D and marketing. Thus, it may foster knowledge dissemination within R&D but hamper knowledge dissemination between R&D and marketing. Furthermore, whereas the duplication of communication by e-mail may cost no more than a little extra effort, the duplication of face-to-face communication may imply a duplication of effort. Finally, when CMC technologies are equipped with a memory function, they are also very able to deal with the longer time scope involved in innovation processes (e.g., Garud and Nayyar, 1994).

From these arguments it follows that the choice for investment in co-location or CMC technologies depends on the scope of knowledge dissemination to be facilitated. The larger the scope of knowledge dissemination, the more CMC technologies are suited for technological knowledge dissemination. Whereas studies of single groups found co-location to be more favorable (e.g., Hightower and Sayeed, 1995, 1996), the SBU level findings of this study suggest that it is more favorable to invest in CMC technologies than in co-location of R&D staff as a means to improve knowledge dissemination.

Knowledge dissemination at the level of the firm differs from knowledge sharing in dyads or groups not only with regard to scope, but also with regard to the heterogeneity of its characteristics. The theory section alluded to the heterogeneity of knowledge dissemination for technology and product development: Both uncertainty and ambiguity must be reduced (Daft and Lengel, 1984); both explicit and tacit knowledge must be disseminated (Nonaka, 1994); knowledge must be disseminated within both weak and strong relationships (Hansen, 1999), in planned and unplanned meetings, and both nearby and far away (Dixon, 2000; Garud and Nayyar, 1994). The surprising result that CMC technologies and co-location of R&D staff were found to be complementary may be explained by this heterogeneity of knowledge dissemination characteristics within technology development. The theory reviewed suggests that co-location and electronic communication are better suited for particular types of communication: electronic communication for explicit knowledge and co-location for tacit knowledge; electronic communication for uncertainty reduction and face-to-face communication for ambiguity resolution; co-location for building trusted relationships and spontaneous encounters and CMC technologies for bridging time and space. It was expected that due to these specific strengths, co-location and IT would have some additional value when the other was already present but more value when the other was not yet present. The findings of this study, on the contrary, suggest that IT and co-location increase each other's value. This can be understood if it is acknowledged that tasks in innovation projects are interdependent (Clark and Fujimoto, 1991). The quality of the execution of one task, and the knowledge dissemination associated with it, enables an improved execution of other tasks. If interdependent tasks involve heterogeneous knowledge-sharing characteristics, the successful execution of those tasks requires a balanced investment in IT and co-location.

For example, the first phases of technology development projects are more characterized by ambiguity about project goals and technological feasibility than later phases (Ajamian and Koen, 2002; Garud and Van de Ven, 1992). Furthermore, building of relationships and trust is typically required in the early phases of projects. Therefore, co-location is more appropriate in the early phases of a technology development project. Communication through co-located meetings in the beginning of a project lays a foundation of shared understanding and trust that enables later communication through CMC technologies. Thus, later knowledge dissemination depends on the presence and quality of earlier knowledge dissemination.

Effective knowledge dissemination requires a balanced investment in co-location and information technologies to be able to deal with the heterogeneous but interdependent types of knowledge dissemination. Management should not consider the choice between investing in CMC technologies or co-location as either/or but as both/and. This also means that the global deconcentration of the R&D function might be a less effective strategy than is generally expected.

Although this study did not focus on cultural differences, the minor differences that were found between the U.S. and Dutch results call for some post hoc reflection. One difference is that the mean score on knowledge dissemination is higher in the Netherlands in three of the four conditions. Especially when both co-location and CMC technologies are low, knowledge sharing is higher in the Netherlands than in the United States. Hofstede's (1980) theory on national cultures offers an explanation for this difference. The United States and the Netherlands have comparable scores on three of the four dimensions discerned by Hofstede. Yet they differ sharply on the masculinity–femininity dimension. The United States has a rather masculine culture, in which achievement and success are important values. The Netherlands has a rather feminine culture, characterized by caring for others and a supportive attitude. The femininity of Dutch culture may make employees of Dutch companies more prone to share their knowledge with others.

This study has several limitations. First, this section has offered theoretical explanations and practical implications of the empirical findings. Of course, these explanations are made after the fact. More effort is required to test these post hoc explanations and to further develop the onset for a firm-level theory. In particular, the idea that the usefulness of CMC depends on the scope of knowledge dissemination must be examined in more detail. The same holds true for the dynamics of the phenomenon under study (e.g., Walther, 1995). A more longitudinal design would overcome the second limitation of this study, namely, that it only used cross-sectional data. Third, this study is restricted to the process of technology development in high-technology firms. In particular, more research is needed on the suitability of co-location and CMC technologies for the later stages of new product development that are not covered by the technology development process. Moreover, future research should consider different stages of the technology development process, since it is known that these stages differ in ambiguity and uncertainty. Also, the cultural differences in the level of knowledge sharing have to be examined in more detail. Finally, future research should include other knowledge processes, such as knowledge integration and application (Grant, 1996; Song, Van der Bij, and Weggeman, 2005) and the dissemination of other types of knowledge.

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Appendix. Constructs, Measurement Items and Construct Reliabilities

Knowledge Dissemination (Construct Reliability: US data 0.85; Dutch data 0.79)

	Strongly Disagree					Neutral				Strongly Agree	
The level of knowledge sharing and disseminating is high in this organization.	0	1	2	3	4	5	6	7	8	9	10
Data on technology development are disseminated at all levels in our company on a regular basis.	0	1	2	3	4	5	6	7	8	9	10
We freely communicate information about our successful and unsuccessful technology development across all business functions.	0	1	2	3	4	5	6	7	8	9	10
There is a lot of cross-functional communication concerning technology developments in our company.	0	1	2	3	4	5	6	7	8	9	10
There are a lot of informal "hall talk" concerning our technology development tactics or strategies.	0	1	2	3	4	5	6	7	8	9	10
Our company periodically circulates documents (e.g., reports, newsletters) that provide new knowledge created.	0	1	2	3	4	5	6	7	8	9	10

Computer-Mediated Communication Technologies (Construct Reliability: US data 0.95; Dutch data 0.81) (adopted from Sethi and King 1994)

The Computer-Mediated Communication Technologies (IT_c) provide ways to enable, intensify, or expand the interactions of multiple agents (e.g., organizational members, departments, etc) in the execution of a planning, design, decisions, or implementation task. There are several possible uses of the IT_c: 1) to help reduce geographical and/or time constraints; 2) to enforce rules, policies, or priorities over development activities and resources; and 3) to improve the sharing and exchange of information across all levels of the organization and/or intra organizations. Examples of the IT_c are: Group Support Systems (GSS), Executive Information Systems (EIS), email, video conferencing systems, web-based conferencing, Electronic Data Interchange (EDI), etc.

Appendix (Cont'd.)

Please provide data for the following dimension regarding the above IT_c systems (please circle a number)

1. The level of the investment in the IT_c relative to the industry norm/standard:												
Much lower than the industry norm/standard	0	1	2	3	4	5	6	7	8	9	10	**Much higher than the industry norm/standard**
2. The availability of the IT_c systems:												
Available to only a few people	0	1	2	3	4	5	6	7	8	9	10	**Available to everyone**
3. The level of state-of-the-art technology in the IT_c systems:												
Much worse than the industry norm/standard	0	1	2	3	4	5	6	7	8	9	10	**Much better than the industry norm/standard**
4. The level of easiness to use the IT_c systems:												
Very difficult to use	0	1	2	3	4	5	6	7	8	9	10	**Very easy to use**
5. The quality of the service of the IT_c systems:												
Long response time	0	1	2	3	4	5	6	7	8	9	10	**Short response time**
Low reliability	0	1	2	3	4	5	6	7	8	9	10	**High reliability**
Not dependable	0	1	2	3	4	5	6	7	8	9	10	**Highly dependable**

Co-location of R&D staff (Construct Reliability: US data 0.83; Dutch data 0.79) (adopted from Pinto et al. 1993)

The physical distance between the different departments of the R&D is: (0 = none; 10 = very far; reversed item).	0	1	2	3	4	5	6	7	8	9	10
The offices of R&D personnel are located in close proximity to each other (0 = strongly disagree; 10 = strongly agree).	0	1	2	3	4	5	6	7	8	9	10
It is easy for the R&D personnel to travel to meet (0 = strongly disagree; 10 = strongly agree).	0	1	2	3	4	5	6	7	8	9	10
R&D personnel often have problems to communicate each other due to the physical separation of their offices (0 = strongly disagree; 10 = strongly agree; reversed item).	0	1	2	3	4	5	6	7	8	9	10