Chapter V

Computer Mediated Interorganizational Knowledge Sharing: Insights from a Virtual Team Innovating Using a Collaborative Tool[1]

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How does a team use a computer-mediated technology to share and reuse knowledge when the team is inter-organizational and virtual, when the team must compete for the attention of team members with collocated teams, and when the task is the creation of a completely new innovation? From a review of the literature on knowledge sharing and reuse using collaborative tools, three propositions are generated about the likely behavior of the team in using the collaborative tool and reusing the knowledge put in the knowledge repository. A multi-method longitudinal research study of this design team was conducted over its ten-month design effort. Both qualitative and quantitative data were obtained. Results indicated that the propositions from the literature were insufficient to explain the behavior of the team. We found that ambiguity of the task does not determine use of a collaborative tool; that tool use does not increase with experience; and that knowledge that is perceived as transient (whether it really is transient or not) is unlikely to be referenced properly for later search and retrieval. Implications for practice and theory are discussed.

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completely new innovation?

This is an important set of interrelated questions because of the increasing use of *virtual interorganizational collaboration* and the development and diffusion of *collaborative technologies* (CT) to facilitate the collaboration process (Allen and Jarman 1999; Coleman 1997; Haywood, 1998; Lipnack and Stamps, 1997). Dow, Ford, Chrysler and British Petroleum are well-known examples of companies diffusing CTs to facilitate their work (Ferranti 1997; Hamblen 1998). A Gartner Group (1997) study went as far as to say: "Real-time collaboration use will change from virtually nothing to ubiquity by 1999" (p.26).

The use of CTs is fundamental to making virtual teams work. A CT, also referred to as a virtual workplace, should be able to record, at a minimum, the process of the group, an agenda, libraries of solutions and practices, different forms of interaction, meta-information (such as date, sequence, author of contributions), and provide shared information storage, access and retrieval (Ellis et al., 1991; Field, 1996; Ishii et al., 1994; Kling, 1991; Nunamaker et al., 1993, 1995; Romano et al., 1998; Thornton and Lockard, 1994).

Critical, then, for knowledge-sharing and reuse with CTs is that the CT includes not just a mechanism for exchanging information (such as e-mail), but a mechanism for creating a knowledge repository and a mechanism for accessing the knowledge repository. In this chapter, we report results from a 10-month field study of an interorganizational virtual engineering design team and describe how a CT is used with respect to knowledge-sharing. The two questions we address are: (1) When do members of a virtual, distributed, interorganizational team designing an innovative new product use a CT to collaborate? (2) When and how do team members reuse the knowledge once it is shared in the knowledge repository of the CT?

LITERATURE REVIEW AND RESEARCH PROPOSITIONS

The criticality of CTs to collaborative work has been well-recognized in the literature (see Eveland and Bikson, 1989; Galegher and Kraut, 1990; Hiltz and Turoff, 1993; Johansen, 1988, 1992; Olson and Atkins, 1990; Rice and Shook, 1990; Romano et al., 1998; Schrage, 1990). Among the many factors affecting the use of CTs suggested by these studies, two are of primary concern to us in this study: 1) *experience* with the CT and 2) *task* being accomplished using the CT.

Experience with a CT is a critical factor because, typically, teams use face-to-face media to share crucial knowledge on the extant norms, habits, and political relationships, in addition to content (Ehrlich, 1987; Kraut et al., 1998; Markus, 1992; Perin, 1991; Rice and Gattiker, 1999; Saunders and Jones, 1990). Over time, however, teams have been observed to gradually adjust to conveying richer information through the collaborative tool (Hiltz and Turoff, 1981; Orlikowski et al., 1995; Walther, 1992).

In addition to experience, studies have also found that not all tasks that a team might undertake to accomplish its objective are best suited for use with CTs. Several theories provide foundations for this perspective: "information richness" theory, "social presence" theory (Daft and Lengel, 1986; Rice, 1984, 1987; Short et al.,1976), and the task circumplex model (McGrath and Hollingshead, 1993). These theories argue that organizational information-processing activities are differentially supported by various media; the attributes of certain media match the information processing requirements of some activities better than others. Because of the kind of information they can transmit (nonverbal cues, etc.), some channels (face-to-face, videoconferencing, etc.) are particularly suited for tasks that are unanalyzable, non-routine, equivocal and involve manageable amounts of information. Unanalyzable tasks that teams might perform include strategic direction-setting, brainstorming, and conflict resolution. For such tasks, the theories predict that, given the option, teams will opt to use what can be called "interpersonal" methods of sharing knowledge since such methods provide the most context-rich capability. The most personal of these methods is the face-to-face meeting. For distributed team members, dyadic phone conversations are not nearly as interpersonal, but they provide at least the opportunity to share information in a one-on-one setting with aural cues. In contrast to these interpersonal methods are computer-mediated collaborative tools that share the information with the entire team. Collaborative tools are generally considered less likely to be used for ambiguous tasks because their public text-based, computer-mediated nature makes it more difficult to share the context-rich information needed to understand the task.

Sharing knowledge and putting the shared knowledge into a knowledge repository are an important start in knowledge-sharing and the basis for organizational memory (Davenport et al., 1996; Huber 1991; Walsh and Ungson, 1991). The repository alone is insufficient, however. For shared knowledge to be meaningfully used, the knowledge needs to be coupled with mechanisms for organization, retention, maintenance, search and retrieval of the information (Stein and Zwass, 1995). Such mechanisms are often computer-based, ranging from simple keyword organizing principles to complex intelligent agents and neural networks that grow with the growth of the knowledge repositories (Ellis et al., 1991; Johansen, 1988; Maes, 1994). Common among all these mechanisms is that they are established at the outset of a project (such as keywords) and are not generally modified during use. Thus, the literature indicates that these mechanisms, if established at the outset to promote knowledge reuse, will generally succeed at promoting knowledge reuse.

Although past research has yielded these important suggestions for the use of CTs, the literature on the use of CTs identifies a whole host of individual, technology, organizational, and group process factors that can also affect the use of CTs in sharing and reusing knowledge (DeSanctis and Gallupe, 1987; Furst, Blackburn and Rosen, 1999; Hibbard, 1997; Rice and Gattiker, 1999; Sambamurthy and Chi,n 1994). Because of the many factors that affect the knowledge-sharing and use process, we contend it is difficult to determine which conclusions from the literature apply in all situations. Others (e.g., Kraemer and Pinnsonneault, 1990) have made similar arguments.

One aspect of a situation that has been little studied is the use of CTs among highly creative teams. Most studies of virtual team knowledge-sharing have been conducted on teams working on defined tasks such as software development. We believe that the decision process for creating an entirely innovative design, such as is called for in "discontinuous technology developments" (Iansiti, 1995; Tushman and Anderso,n 1986), is fundamentally different than making decisions about problems for which there is a known solution or process because the brainstorming is neither anonymous nor non-evaluative, the knowledge to be shared is highly contextualized and reliant on informal opportunities of physical proximity, and knowledge-sharing involves not just synthesizing information but dissecting and recreating that knowledge in fundamentally different ways (Allen 1985; Davis 1984; Kraut et al. 1990).

Given these characteristics of knowledge-sharing in creative contexts, conclusions about how CTs are used to share knowledge among team members with more routine tasks may not apply. For example, for creative tasks, the theories noted above all suggest that knowledge-sharing be performed face-to-face. However, for a creative design team, this would mean that most if not all their work be done face-to-face. Such a conclusion seems too extreme and negates the purpose of virtual design teams.

In sum, then, a situation that has particularly been under studied is the use of CTs for knowledge-sharing among: a) distributed team members b) working collaboratively c) across organizations d) via a collaborative tool to e) create a revolutionary new product. As a starting point, we used the suggestions from the literature on using CTs for knowledge-sharing and knowledge reuse as propositions to be examined for this special population of virtual teams.

We examined two propositions for using CTs to share knowledge:

Proposition #1) A distributed virtual team will initially show little use of CT, but its use of CT will increase over time as the members gain more experience with it.

Proposition #2) When a distributed virtual team performs highly ambiguous tasks, the members will use person (face-to-face or phone) more than CT-based media; but when the task is less ambiguous, the members will use the CT more.

We examined one proposition for using CTs to reuse knowledge:

Proposition #3) Establishing technology features and mechanisms for knowledge reuse at the beginning of a project will prompt the virtual team to reuse knowledge during the course of the project.

RESEARCH DESIGN

Site, Sample, and Project

We explored these three propositions through a longitudinal research study of an engineering design team for the 10 months during its conceptual design process. The team involved eight engineers spending a small (<15%) fraction of each of their total work time from three different companies (RocketCo, 6SigmaCo, and StressCo as pseudonyms); the project was referred to by the code name for the product, "Slice". Their goal was to design a new form of a rocket engine thrust chamber. The engineers were organized into a traditional concept development team consisting of a project team leader, conceptual designer, lead design engineer, design engineer, stress analyst, aerothermal analyst, combustion analyst, and a producibility analyst.

The Slice team's design task was a highly innovative one: to design a high-performance rocket injector using combustible fluids that had not been used together previously in RocketCo, at a manufacturing cost that was a significant reduction over what had been previously achieved. The innovation of using a different combination of fluids meant that knowledge of fluid dynamics and combustion behavior acquired from previous designs could not be applied directly to this one. As a result, the design process became more iterative than usual, one in which ideas were generated, analyses performed, guesses made, and ideas thrown out when people didn't seem convinced of the idea's feasibility or analysis results.

In addition to the product innovation, the team was tasked with the explicit objective of innovating in the use of a collaborative tool among geographically dispersed team members; this also represented an innovation for the company. As a result, they saw that part of their effort was not only to design a product (a rocket thrust chamber), but to develop a new process (use of a collaborative tool). Finally, the fact that three companies were involved in this early stage of concept development was new, especially for RocketCo, which considered rocket engine design its core competency. The other companies were included because they had core competencies in producibility engineering and stress analysis, which are crucial components in the initial development of a rocket engine.

Despite all the complexities faced by the team and a poor mid-project review by senior technical managers, by the end of the project, the team was judged by the senior managers in RocketCo as successfully achieving its objectives. The team designed a thrust chamber for a new rocket engine with only 6 parts instead of the traditional hundreds, with a predicted quality rating of 9 sigma (less than 1 failure out of 10 billion) instead of the traditional 2 to 4 sigma, at a first unit cost of $50,000 instead of millions, and at a predicted production cost of $35,000 instead of millions. The team was able to achieve all of this with no member serving more than 15% of his time, within the development budget, with total engineering hours 10 times less than traditional teams, using a new collaborative technology with several partners having no history of working together. Finally, senior management has been sufficiently impressed with the design to approve it for the next step in the development process: a cold flow test assessing the validity of the assumptions of liquid flow through the parts.

Thus, this study provides an excellent opportunity to observe a highly successful virtual team using a CT to accomplish its task.

Description of the Collaborative Technology

Team members had two types of communication channels available to them: interpersonal (which included face-to-face for a few members in RocketCo, three team-wide meetings, and the telephone for all members), and the collaborative tool (e-mail was infrequently used).

The collaborative tool available to them was called The Internet Notebook ("Notebook"). This CT allowed team members access to a project knowledge repository which was housed on a centralized server located at the tool vendor's site. The Notebook was typically launched as a helper application from an HTML browser. Each time a team member would log-on to the central server, he could either just view the notebook without launching the Notebook application, or he could launch the full application. Launching the application provided the engineer with both the knowledge repository as well as such useful capabilities that permitted authoring new documents (called entries), commenting on entries in the Notebook, sorting entries by date, keyword or reference links, navigating to find entries, creating sketches using a whiteboard, "snapshotting" and hot-linking screen displays from other applications, creating a personal profile for email notification of relevant entries, using templates for frequent team activities (such as minutes, agendas), and vaulting documents requiring configuration control.

Team members could use the CT asynchronously or synchronously. Asynchronous use of the Notebook meant that a team member could make an entry into the Notebook with appropriate team members automatically notified of the entry, and then those notified members could comment on the entry and republish it. Team members also used the Notebook for synchronous team meetings which they called "teleconferences". These meetings consisted of the application-sharing Notebook for data only, and audioconferencing on a separate channel, supplemented with the Notebook's full functionalities. This is referred to by the Gartner (1997) group as the "down and dirty" approach to synchronous communication.

Data Collection Methodology

Since virtual teams evolve through different phases depending on the stages of the design project, we used a multi-method longitudinal study design (Menard, 1991):

1. Ethnographic observation (Geertz, 1973; Harvey and Myers, 1995; Hughes et al, 1992; Orlikowski and Robey, 1991) of all 89 one-hour teleconferences and three in-person team meetings (at the kickoff, at mid-project, and at the end).
2. Panel questionnaire surveys of the eight team members at the three stages in the project: inception, for each of the 40 weeks during, and at the project, end to collect data on team members' background, use of communication media, attitudes toward communication media, and satisfaction with team process. Standardized instruments were used and are available upon request.
3. Weekly communication network diaries completed by team members.
4. Interviews with team members after critical events.
5. A "Lessons Learned" group meeting conducted with the team members at the end of the project.
6. Weekly logs of electronic traffic using the Notebook among team members.

FINDINGS FOR PROPOSITIONS FOR USE OF CT IN KNOWLEDGE-SHARING

Findings on Proposition 1: CT Use Will Increase Over Time

Across the entire project, the team members collaborated with others 61% of their time, with the rest of the time spent in activities they could perform themselves (e.g., drawing, analysis, report-writing, etc.). We observed the choices the team members made on whether to use interpersonal media (such as face-to-face or phone) or collaboration tool support when they collaborated with others. Following our initial expectation and that of the literature's, we anticipated that the use of interpersonal media would be high initially and reduce over time while the use of the collaborative tool would be low initially and gradually increase over time.

Figure 1 presents the weekly data over the course of the 10 months of the project. While on the average, across the time-span of the project, the team members used interpersonal methods (face-to-face and phone) 37% and the collaboration tool 63% of the time, there were wide fluctuations in use. Instead of a gradual increase in CT use, we found

Table 1: Modes of Communication

	Primary Method Personal FtoF + Phone	Primary Method Public TeleConf + Notebook	Secondary Method Personal FtoF + Phone	Secondary Method Public TeleConf + Notebook	Mean % Personal Primary & Secondary	Mean % Public Primary & Secondary
1 …clarify team members' roles and relationships.	38%	63%	38%	63%	38%	63%
2 …clarify project objectives and priorities within the team.	13%	88%	50%	50%	31%	69%
3 …clarify project objectives and priorities with those outside the team.	75%	25%	83%	17%	79%	21%
4 …change project objectives, priorities, or specification.	13%	88%	50%	50%	31%	69%
5 …recall technical specifications and constraints.	0%	100%	25%	75%	13%	88%
6 …sketch out ideas for injector concept.	50%	50%	50%	50%	50%	50%
7 …transform concept sketch into injector drawing.	50%	50%	67%	33%	58%	42%
8 …learn about unfamiliar parts of the concept.	25%	75%	38%	63%	31%	69%
9 …understand the design concerns of other team members.	13%	88%	50%	50%	31%	69%
10 …get up to speed on current concept.	13%	88%	25%	75%	19%	81%
11 …share own design expertise with others.	25%	75%	71%	29%	48%	52%
12 …identify areas requiring more detailed evaluation.	25%	75%	50%	50%	38%	63%
13 …quickly generate new ideas.	38%	63%	75%	25%	56%	44%
14 …compare competing concepts.	0%	100%	13%	88%	6%	94%
15 …focus analysis on important design issues.	13%	88%	38%	63%	25%	75%
16 …examine design tradeoffs.	0%	100%	25%	75%	13%	88%
17 …jointly author a document or joint analysis.	25%	75%	63%	38%	44%	56%
18 …quickly identify disagreements.	13%	88%	88%	13%	50%	50%
19… quickly resolve conflict over design approach.	25%	75%	75%	25%	50%	50%
20… determine next steps in the design process.	38%	63%	50%	50%	44%	56%
21 ..coordinate activities within the team.	0%	100%	88%	13%	44%	56%
22 …get appropriate team members to participate	75%	25%	63%	38%	69%	31%
23 ..move project forward when stalled.	29%	71%	86%	14%	57%	43%
24 …resolve design conflicts with others outside the team.	88%	13%	75%	25%	81%	19%
25 …obtain resources or information outside of team.	88%	13%	100%	0%	94%	6%
26 …monitor program status and documentation. asking: "To what extent do you believe that …"	0%	100%	13%	88%	6%	94%

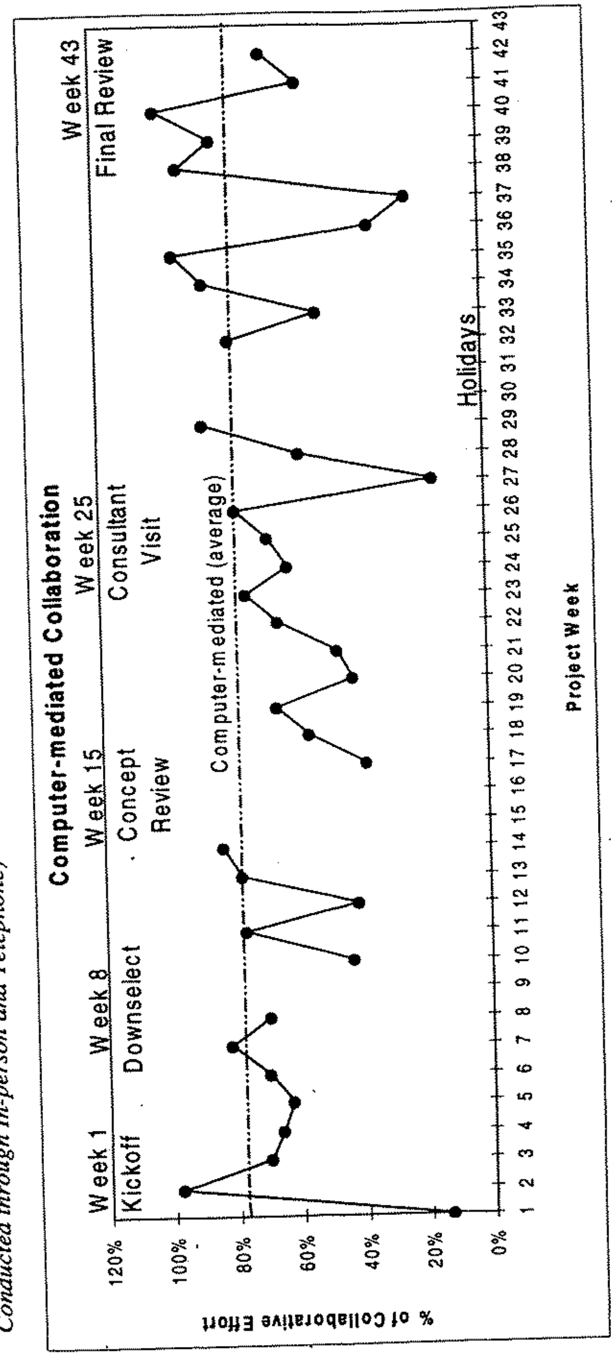

Figure 1: Percent Collaboration Conducted through Computer-mediated Communication by Week (Remaining Percent Conducted through In-person and Telephone)

that the members quickly learned the tool and began to use it at a moderate level of use, with enormous peaks and valleys throughout the project, but never showing a consistent trend of increasing. Thus members did not increase their usage over time compared to more interpersonal media of face-to-face and phone.

Findings for Proposition 2: CT Use Will be Less for Ambiguous Tasks

The literature had suggested that face-to-face was more likely to occur with strategic direction-setting, creative brainstorming, and conflict resolution on the design concept. Table 1 shows the results of the questionnaire given to the members at the end of the project asking them to indicate which communication media they actually used primarily and secondarily. Apparent from Table 1 is that, as expected, the team members indicated that they tended to use face-to-face or phone for the more ambiguous tasks of managing external relationships and conflicts (including obtaining resources or information outside of the team, resolve design conflicts with others outside the team, and clarify project objectives and priorities with those outside the team, get appropriate team members to participate), brainstorming (e.g., quickly generate new ideas, transform concept sketch into a thrust chamber drawing), and strategic direction-setting (e.g., move project forward when stalled, clarify project objectives). Also, as expected, they tended to use the synchronous CTs for the more routine tasks of analysis (e.g., comparing competing concepts, examining design tradeoffs, focus analysis on important design issues), and project statusing (monitor program status and documentation, get up to speed on current concept, and recall technical specs and constraints).

In addition, however, the questionnaire data indicated that the CT was used for more ambiguous tasks as well. Such tasks as clarify project objectives, change project objectives, learn about unfamiliar parts of the concept, and understand the design concerns of other team members — clearly non-routine tasks — were performed by the team members, on the average, using the CT 69% of the time (versus face-to-face or phone). This clearly indicates that members were able to adjust to the use of CTs for more ambiguous tasks.

Observations of the team also indicated that the team was able to use CTs for more ambiguous tasks. In particular, the intense, creative "grab-the-pen" variety of brainstorming was initially accomplished only through a face-to-face meeting, but later in the project was accomplished using the CT.

Why was the team able to do brainstorming using the CT at the end of the project while they couldn't at the beginning? We believe it had to do with the artifacts and the shared language that came about from the earlier efforts. At the only face-to-face brainstorm, the team members came up with a first-cut design which, even though was very different from the final design, was instrumental in establishing an artifact around which team members could now work virtually. They used that artifact to explain the underlying physics of combustion and to explain the fundamentals of their disciplines to other team members. In addition, during the earlier meetings, experts spent time explaining the technical reasons for rejecting concepts, which paid off later in the project when other team members detected similar problems encountered earlier. Nonaka and Takeuchi (1995) stress the importance of such shared understanding for enabling knowledge transfer among collaborators.

What created this shared language? Certainly the first two face-to-face meetings provided an important medium. In fact, several members commented that more in-person meetings to resolve conflicts would have been helpful. However, we believe that the ability of the team to create a shared language was also partially attributable to the departure of the initial combustion analyst and conceptual designer — a turnover that eventually led to a more homogeneous team. In a sense, the brainstorming at the beginning was over fundamental differences of opinion, while the brainstorming at the end accepted certain fundamental assumptions. As a result, brainstorming at the end could focus on idea generation and critique, rather than resolution of inherently unresolvable conflicts over assumptions and approaches. Note that in this instance, the richer face-to-face medium can be seen as exacerbating the divergent group norms, while the leaner CT can be seen as facilitating the use of a convergent group norm.

In sum, we learned that sharing knowledge virtually using a CT is not determined solely by the ambiguity of the task but rather by the identification of a common language and artifacts through face-to-face communication. Once the commonality is created, even ambiguous tasks such as creative brainstorming can be performed using CTs. In addition, the use of a CT does not increase as experience with the tool increases, but rather varies with the task at hand, and not necessarily because of task ambiguity.

Findings for Proposition 3: CT Features Will Prompt Knowledge-Reuse

Team members were very interested in encouraging reuse of the knowledge generated by the team. Therefore, at the outset of the project, selected members of the team spent significant time developing a Coordination Protocol that identified ways to use features of the CT that would increase team members' ability to reuse knowledge. This protocol encouraged the use of reference links and keywords when entering knowledge into the CT; using templates for meeting agendas, decisions, action items, and meeting minutes; and being automatically notified when entries relevant to a members' interest were created. The members who created the protocol obtained concurrence from the team to use the protocol and then trained all team members in its use. Thus, we proposed that these features and the protocol would succeed in creating reuse among the team.

Again, the team fooled us. Although in the beginning the members agreed to the standards for keyword use, as the design effort began in earnest, keyword use and reference links quickly fell to the wayside. Only 37% of the entries had two or more keywords and only 27% of the entries had three or more. Members turned off their notification profiles, because, when an entry was republished many times, they would receive too many email notifications (e.g., 621 notifications generated for the keyword "design" in the first 2 weeks of the project). The variety of f templates available were not used as often as expected, with only the "meeting minutes" template still being used midway through the project. Finally, members rarely used the more sophisticated navigation features of the tool (such as the ability to view networks of entries in accordance with the frequency with which they referenced each other); instead most relied on finding entries by reviewing them in their chronological order (looking at those they had arrived since they last looked into the Notebook) with only occasionally even doing a quick top-level keyword search (e.g., search on the keyword "minutes" to find the minutes of a meeting missed).

The questionnaire data from the team members provide additional insight into the use of the CT's features for search and retrieval. Team members were asked the frequency with which they used various features of the CT. Table 2 shows the frequency of use for each. The only feature used relatively frequently (slightly more than 2-3 times a month) was the documentation of work in the public Notebook. In sum, the team made little use of the supposedly powerful organization, search, and retrieval mechanisms provided by the CT.

*Table 2: **Frequency of Notebook Usage during Project***

Feature	Mean	Std Dev
Documentation in public notebook	4.5	1.4
Documentation in personal notebook	2.9	2.0
Navigator	3.3	1.8
Reference Links/Hot Links	3.6	1.2
Templates	2.1	0.9
Snapshot	3.4	1.7
Sketching via Notebook tools	2.4	1.5

Note: Scale consisted of "1" - Never during project, "2" - Less than once a month, "3" - Once a month, "4" 2-3 times a month, "5" - Once a week, "6" - 2-3 times a week, "7" - Daily.

What explains the team's use of the knowledge repository in this way? We found that the design process was so unpredictable that most of the members had no clue as to whether or not the knowledge they were putting into the database would be of value later on and thus those entries did not warrant attempts at categorization and organization. Since designs were changing almost biweekly (with over 20 design concepts generated during the ten months represented in 60 entries), analysis results relevant to a particular design might be obsolete a week later. Since management was seen as changing their directions throughout the project, entries of discussions of strategy and goals were often of limited value a month later. Since drawings were often being redesigned, a drawing might or might not have features and dimensions that would be of use in later designs. We believe that the fact that some knowledge may be perceived to only have what we call "transient utility" has an effect on what gets entered and how it gets entered and recalled.

In other words, because information was changing so rapidly, team members didn't bother to waste their time to attach keywords or reference links. As a result, keyword searches and networks of linked documents quickly became useless. Moreover, because the information was transient, it was hard for them to even see a pattern to the entries in order to suggest new keywords. In fact, at the end of the project, one team member suggested wistfully: "You know, it would have been a good idea if we had created a new keyword for each new concept so that we could search easier"; even this suggestion at structure was critiqued by another member, who pointed out: "How could we? We often didn't even know when we were doing a new concept rather than just a revision to the existing concept".

Was the lack of organization a problem for retrieving needed information? Despite members believing that virtually all entries were transient, in reality, many entries were referenced in conversations later on. By the end of the project, there were almost 1000 entries: 661 generated by the design team, with the remaining for Notebook administration, testing, and pre-kickoff discussions. To look for previous entries, then, took significant amounts of time during a meeting. Moreover, even though reference links were used only 19% of the time, the team members reported, in Table 3, that, when the reference links were created, they were the most useful features for finding information quickly since they helped to trace back to those documents that were the most relevant to their

search needs.

Given that the links were considered as having the most potential use for finding information quickly, what barriers need to be removed for engineers to consider using them, especially for what might appear, at first sight, to be "transient knowledge"? To address this question, we asked the team members, at the end of the project, to indicate their agreement with a series of assumptions that tool vendors make about how engineers might use CTs to facilitate their collaboration (Ellis et al., 1991; Grudin, 1988, 1994; Ishii et al., 1994; Johnson-Lenz and Johnson-Lenz, 1982; King and Majchrzak, 1996; Kling, 1991; Malone et al., 1987; Nunamaker et al., 1993). Table 4 shows these results. While team members agreed that a CT and an accessible knowledge repository are valuable assets to their work, such assets will have limited value for

Table 3: Usefulness of Notebook Features in Finding Relevant Information Quickly

Feature	Mean	Std Dev
Authoring Notebook entries	3.6	1.3
Snapshot	3.6	1.3
Sketching	2.8	1.2
Navigator	2.8	0.8
Notify via email of new/changed entries	3.5	1.3
Reference Links	4.6	0.7
Hot Links	4.8	0.4
Template	2.3	1.2
Remote access	3.8	1.3

Note: Scale anchored from "1", definitely useless, to "5", definitely useful.

Table 4: Assumptions About Use of Electronic Notebook

Item	Mean	Std Dev
Engineers need not only a collaborative tool, but also a personal knowledge storage tool.	5.9	0.9
Engineers need to access their own documents while traveling or away from their desk.	5.5	1.7
Engineers want to quickly access old documents.	6.0	1.0
Engineers want to see the connections (links) among old documents.	5.5	1.0
The data structure represented by the links helps engineers understand the content of the document before opening it.	3.3	1.6
When an author publishes a document, he/she will choose the appropriate keywords	3.4	1.5
Set of selected keywords are accurate classifications of the document content.	2.6	1.0
Engineers can easily determine which documents should be linked together.	3.5	1.7
Engineers will make an effort to make (link) the connections among documents.	3.0	1.5
Templates help engineers organize their thoughts.	2.5	1.6
Templates help engineers collect structured data.	3.1	1.8
Engineers want to be automatically informed when documents of interest are published (or changed).	5.8	0.8
When engineers specify their personal profile, they understand the exact meaning of the keywords.	3.3	1.2

Note: 1 to 7 anchored scale from "1" - Not at all to "7" great extent, knowledge reuse unless such knowledge search mechanisms as reference links require less discipline by the team member to maintain, and quickly provide more information to facilitate a search process, and the bulk of knowledge is not of transient utility.

In sum, both the questionnaire and observational data suggest that knowledge reuse by a team using CT is not facilitated with existing mechanisms for search and retrieval when the knowledge informant considers the knowledge to be transient; can not be aided by a set of keywords created in the abstract prior to actual use of the CT; and can not be aided by user-governed reference-linking mechanisms which impose too much burden on the user.

CONCLUSIONS

From our detailed and longitudinal examination of how members of a distributed, virtual, interorganizational creative design team shared and reused their knowledge using a collaborative tool, we found that propositions from the literature were insufficient to inform either theory or practice on the use of collaborative tools.

The information-sharing literature must begin seriously considering the contingent conditions involved in the novel setting of a virtual distributed interorganizational creative team (such as organizational context, team structure, group composition, team norms, building team identity, trust, team cooperation and heterogeneity, process losses, social loafing, groupthink, criteria for group process effectiveness, and material group resources (Furst, Blackburn and Rosen, 1999). However, in spite of the lack of frequent informal or face-to-face interactions, this team was extraordinarily innovative and successful. Very little of the communication here was of the "formal" type (i.e., reports, documents, articles) even if for the simple reason that there were few precedents for the designs, so most of it involved sharing between individuals through attempts at direct solutions. Thus CT designs for such groups should not over-emphasize formal channels, even when technologically possible, and should allow ways to incorporate more "rich" forms of interaction even through the CT itself. Further, it is clear that a fair amount of "mutual expectations" and shared understandings had to be developed before the group could move into a period of focused design process (Krauss and Fussell 1990; Schrage 1990).

In addition to the rejection of commonly accepted propositions in the literature for more routine work environments, our study demonstrated that although most CTs claim to support the exchange of ideas, opinions, and preferences within the group, the document database features that are currently available in most collaborative tools mainly serve as an information repository, not a gateway to the right information, or a process for developing shared cognition. Most navigation tools (search by keywords or links, for example) are not sufficient enough to achieve the purpose. One possible solution to this problem is to create a Knowledge Management role on the team. By organizing the information and collectively monitoring various information sources to ensure information integrity and accuracy, within the rich and transient contexts of the group and the project, the knowledge manager can lower knowledge gathering and monitoring costs of each team member. The fact that early studies of computer conferencing arrived at the same general conclusion — the need for a human process mediator to help support, motivate, and essentially reinforce the group identity and purpose (Kerr, 1986) — reinforces the validity of this suggestion.

ENDNOTE

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