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RADICAL INNOVATION WITHOUT COLLOCATION: A CASE STUDY AT BOEING-ROCKETDYNE[1, 2]

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Abstract

This paper describes how a unique type of virtual team, deploying a computer-mediated collaborative technology, developed a radically new product. The uniqueness of the team—what we call VC^3 teams, for Virtual Cross-value-chain, Creative Collaborative Teams—stemmed from the fact that it was inter-organizational and virtual, and had to compete for the attention of team members who also belong to collocated teams within their own organizations. Existing research on virtual teams does not fully address the challenges of such VC^3 teams. Using the case of Boeing-Rocketdyne, we describe the behavior of members of a VC^3 team to derive implications for research on virtual teaming, especially for studying teams within emerging contexts such as the one we observed. The data we collected also allowed us to identify successful managerial practices and develop recommendations for managers responsible for such teams.

Keywords: Virtual teams, supply-chain collaboration, innovation, collaboration technology.

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Introduction

Suppose there is a ship carrying a team given the task of creating a radical innovation. The product development manager realizes that to achieve truly radical innovation, she must include people who not only have never shared the same ship, but also have never shared the same ocean, the idea being that cross-fertilization of ideas would lead to development of radically new products. That is, innovation will come from bringing people together from different companies, disciplines, products, markets, processes, and industries. Such a ship is hard to steer because the members do not have a common language. They are experts in very different disciplines, different companies, and different products. They share no common history of design, or previous experience working together.

But suppose we are not satisfied with even this possibility of innovation and we realize that, by putting people onto a ship to work together, they are leaving their parent companies. Ironically, we don't want the people who will come—the "best available"—those people the parent company is willing to have leave. We want the best and the brightest that the company has to offer; the person who deeply understands the company's core competency, not just uses it; the "best able," However, because these people are the best, they are already involved in many internal company projects. How do we get them on our ship?

We don't. We dismantle our ship, send everyone home, and create a virtual ship where everyone works on the creative project from his or her desktop, so that team members can remain available to both their parent organization and the creative team. In fact, we make sure we pick people who were never on the same ship so that creativity is the only way out for this team. Such teams essentially become focused SWAT teams, with little history working together, brought together to create revolutionary new concepts on a part-time basis and then disbanded. Because they are virtual, they are never truly "brought together"; rather the members are appointed to the team one day and begin their work from their desktops the next. We call these teams Virtual Cross-value-chain Collaborative Creative teams (or VC^3 teams).

If inter-organizational creative teams are hard to steer, and if virtual teams in general are hard to steer, then VC^3 teams are even harder. Moreover, how does a manager facilitate knowledge-sharing in such an environment: where there is no common history to establish knowledge-sharing norms? Achieving the benefit of radical innovation was one of the initial drivers and hopes of virtual teaming (Davidow and Malone 1992; Ring and Van de Ven 1994); thus, for researchers to understand how to ensure effective knowledge-sharing in such teams will contribute to fulfilling this initial dream.

What Does the Virtual Teaming Literature Suggest for Managing a VC^3 Team?

Research on virtual teams (Duarte and Tennant 1999; Furst et al. 1999; Johansen 1992; O'Hara-Devereaux and Johansen 1994) has typically examined cross-functional virtual teams within firms. Research on cross-organizational virtual teams is quite limited (DeSanctis and Monge 1999). Existing research has generally focused on managing virtual teams, such as motivating team member involvement (O'Hara-Devereaux and Johansen 1994), enhancing team members' identification with the group or organization (Nemiro 2000; Wiesenfeld et al. 1999), managing group process losses (Finholt et al. 1990), and building trust (Javenpaa and Leidner 1999).

Only a small subset of this research has focused on knowledge-sharing in virtual teams, articulating the types of knowledge content shared, norms developed for sharing, and the effect of knowledge-sharing practices on team outcomes. An even smaller subset has focused on knowledge-sharing in inter-organizational virtual teams This research has found that knowledge-sharing in virtual teams is facilitated by evenly distributing knowledge to all team members (Cramton 1997), communicating knowledge of both content and context (Cramton 1997), ensuring that informal knowledge-sharing opportunities are not suppressed (Kraut et al. 1990), and allowing for decision processes to not become too explicit to be monitored by others (Bowers 1995). Underlying these findings is the long held recognition that effective electronically-mediated communication, collaboration, and coordination rests on a shared understanding among team members about the problem, norms (of knowledge capture, sharing, and use; of work distribution; and of roles and responsibilities), and context for interpreting knowledge (Clark 1996; Clark and Brennan 1991, 1993; Davenport and Prusak 1997; Dougherty 1992; Krauss and Fussell 1990; Madhaven and Grover 1998; Marshall and Novick 1995).

For the virtual team to have such a shared understanding usually requires that members start with a common set of norms, context, and problem definitions, either because they have worked together previously, or they have worked in the same organization, product line, industry, or discipline. For example, Ahuja and Carley's (1999) virtual team in a research organization consists of individuals with long-standing relationships (some since the early 1980s). Wiesenfeld et al.'s virtual teams were from the same sales department of a company.

For some virtual teams, there is no shared understanding when the team is initiated because the team members belong to different companies with no previous working relationship. In this case, the shared understanding must be created. Most virtual teams studied to date that must create (rather than use) this shared understanding do so by collocating the team members for a period of time at the beginning of a project when the work process is the most creative, contentious, and likely to require significant consensus-building (DeMeyer 1991; Haywood 1998; O'Hara-Devereaux and Johansen 1994; Zack 1993).[3] Once shared understanding is created, team members and tasks are dispersed back to their home organizations and locations, with future discussions coordinated through computer-mediated communication using the shared social context generated at the outset. For example, when Daimler and Chrysler merged, they organized a virtual team of people from the purchasing departments in Detroit and Germany. The cultures and procedures of the two companies before the merger were so different that, initially, the virtual team members had difficulty even communicating. Team members were then brought together for a multi-day meeting and social activities to "get to know each other" and then sent back home to continue their purchasing activities as a virtual team.

Bringing a team together in a single collocated meeting may be feasible if the team's task is constrained to a limited set of possible solutions using a known decision process. In this single meeting, the solution space, decision process, roles, and responsibilities can be decided upon and people can disperse to work on their tasks. However, there is a limitation to this model of virtual teaming in which collocation creates the shared understanding. This model presumes that the concept, roles, context, and norms can be created at the outset in a collocated meeting and the virtual team's task is to refine or carry out these expectations. But what about the dynamics when it is the creation of the initial concept itself that is the task of the virtual team?

When the task is a highly innovative one, as is the case with VC^3 teams, the methods used to create shared understanding for teams that can distribute their work or follow routine work processes may not apply. Creative work is substantially different from routine problem-solving in the following ways: (1) solutions demand synthesis of domain specific knowledge (Kalay 1989), (2) solutions are generated in unpredictable ways (Safoutin and Thurston 1993), (3) tools to evaluate ideas are without precedent so that both the analysis and solution need to be generated concurrently (Henderson and Clark 1990), (4) the design process is a series of seemingly unresolvable tradeoffs, with priorities among tradeoffs emerging as the design progresses and the process gradually builds a consensus around the solution that meets these priorities (Fox 1993), (5) problems are often not well-specified, being understood only as they are solved (Sage 1992), (6) tasks cannot be easily apportioned to individuals since everybody makes an unpredictable contribution to the process (Hubka and Eder 1996), and (7) expectations evolve (rather than are fixed and followed) about the task, work, collaboration, context, jargon, and assumptions (Gabarro 1990; Krauss and Fussell 1990).

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[3]An exception to this is Javenpaa and Leidner's (1999) study of virtual teams that needed to create a shared understanding entirely virtually; however, their focus was on examining how the team's practices led to increased trust, not knowledge-sharing.

While there have been studies of virtual teams characterized as innovative, the teams rarely fulfill all of these characteristics of highly innovative cross-value-chain teams. For example, while software development is typically considered an unstructured and non-routine task (Kraut and Streeter 1995), software development is divisible, i.e., it is decomposable into small modules to be developed independently, with the modules integrated into a common product. In fact, this is considered best-practice software development. This divisibility does not preclude informal interaction, but it does allow some work to be accomplished without interaction as well as the clear assignment of roles—features not found in highly innovative work.

These characteristics of highly innovative teams suggest that a single collocated session is insufficient to work out the expectations about the process, problem, or solution in VC^3 teams. In non-virtual creative teams, continuously collocated meetings would be held to allow the shared understanding to evolve as new information and ideas are developed. However, continuously collocated meetings violate the precept and associated benefits of virtual teams. Moreover, these characteristics of highly innovative teams call into question the applicability of existing theories used to explain behavior in virtual teams. For example, Jarvenpaa and Leidner point out that Meyerson et al.'s (1996) theory of swift trust assumes clear role divisions and periodic face-to-face meetings. As another example, McGrath's (1991) time, interaction, and peformance theory suggests that consensus formation is best reserved for face-to-face. But, if the team is continuously in a consensus-formation mode, as is the case in a team generating, evaluating, modifying, and discarding new design alternatives each week, this would suggest that consensus formation cannot occur virtually. We argue, therefore, that highly innovative decision processes demand virtual knowledge-sharing that is distinct from the knowledge-sharing typically observed in research on virtual teams. Table 1 summarizes the distinctions.

The opportunity to observe a VC^3 team over time allowed us to address certain fundamental questions about how to manage the knowledge-sharing process in VC^3 teams:

- In what ways do processes of collocated creative teams need to be adapted to suit the knowledge-sharing needs of a VC^3 team?

- How are the obstacles of a lack of initial shared understanding overcome in a cross-organizational virtual environment? What impact does it have on knowledge-sharing in the team?

- How are the obstacles to knowledge-sharing among team members overcome in a virtual environment?

- How does the team ensure that team members do not feel left out from the knowledge-sharing process of the team, especially if certain team members resort to in-person, one-on-one interactions with some collocated (or nearby) team members?

- What steps can be taken or roles created to make sure that appropriate knowledge is stored in the best possible manner for future retrieval and is accessible to team members with minimum search effort?

These are some of the issues that were addressed by Boeing-Rocketdyne and several other partners in a VC^3 team. The team succeeded beyond management's expectations. The authors of this paper were fortunate to be able to observe the team closely throughout its 10-month life and learn how the team eventually addressed these issues. It is their story to which we now turn.

The Case of Boeing-Rocketdyne

The team, called SLICE for Simple Low-cost Innovative Concepts Engine, was initiated by Boeing-Rocketdyne, the major manufacturer of liquid fueled rocket engines in the United States. Rocketdyne's rocket engines were facing new competition in an expanding market driven by the need for commercial launches of communications satellites. Rocketdyne's business objective with SLICE was to be able to drive the cost of a rocket engine down by 100 times, be able to get the

Table 1. Challenges of a VC³ Teams

Management Factors	In the case of virtual teams...	In the case of Boeing-Rocketdyne VC³ Team ...
Objectives of the team	• ...clearly defined objectives and tasks (e.g. software development)	• ...emergent new design with ever changing tasks
Development of shared understanding	• ...members often bring shared understanding to the team through a common allegiance to a profession or organization	• ...shared understanding must be created since there are no common allegiances
Frequent opportunities for interaction with team members	• ...opportunity for collocation from time-to-time allows for spontaneous face-to-face interaction—albeit minimal	• ...with members having primary obligation to their own company, collocation is infeasible; all interactions were through virtual media only
Role definition	• ...roles can be well-defined at outset, aiding team success	• ...roles must be flexible to respond to emerging task, problem, and solution
Coordination norms	• ...communication protocols about what gets communicated to whom, when, and how, can be established at the outset and aid team success	• ...communication protocols are difficult to define upfront since team needs change

engine to market 10 times faster than it had been able to for the Space Shuttle main engine, and increase the useful life of a rocket engine by a factor of three. The breakthrough nature of this task cannot be underestimated: in the beginning, none of the senior technical managers at Rocketdyne—who collectively had hundreds of years of experience designing rocket engines— thought that it was possible; only an advanced program manager was willing to try it.

The key participants in the SLICE team included eight people: a project team leader, concept designer, lead engineer, combustion analyst, and thermal analyst from two different geographically-separated organizations in Rocketdyne; a manufacturability engineer and CAD (Pro-Engineer) specialist from Raytheon (then Texas Instruments) located 1,000 miles away, and a stress analyst from MacNeal-Schwendler Corporation, located 100 miles away. These individuals were picked to work on the team because of their highly valued (world class) expertise in their specialty disciplines. Team members from Raytheon and MacNeal-Schwendler, as well as the project leader, did not have rocket engine design experience, so the team did not share a common understanding of the process by which rocket engines are designed. The team members had never worked together on previous team activities and thus they did not have a common set of norms for coordinating. The team worked for 10 months on the project, with no team member devoting more than 15% of his or her time. Since time was precious, the team opted to minimize travel; as a result, the only time that all members were collocated at a team meeting was the last day of the project at the final technical review and celebration. However, at the one-day kickoff session, in which the team received training in the collaborative tool, six of the eight members were present.

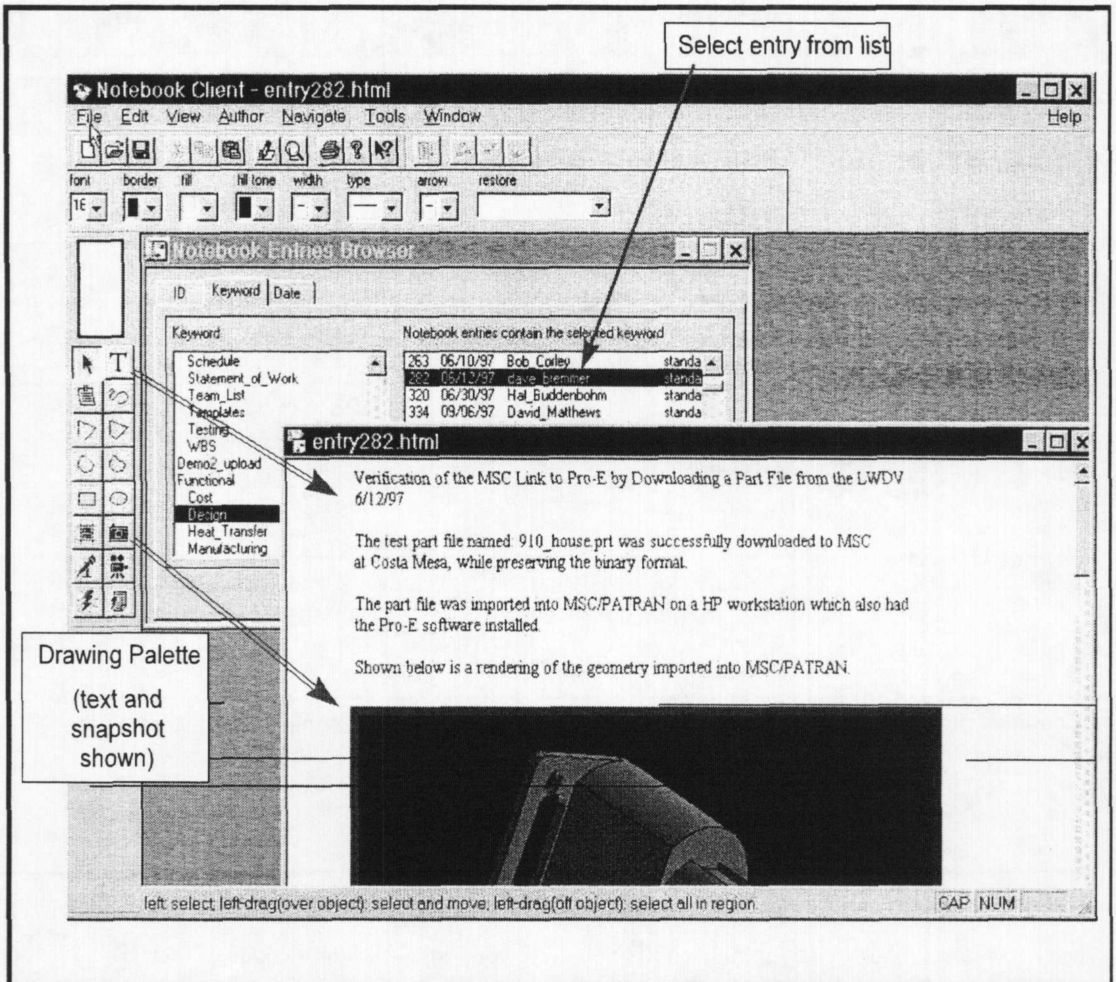

Figure 1. Internet Notebook Interface

The team faced many challenges. They needed to solve a product development problem in a truly innovative way. The team needed to perform its work virtually without the benefit of face-to-face meetings using a new collaborative technology (see Figure 1). The team was comprised of people from different disciplines, different product experiences, different organizations, and different design processes who had never worked together. Finally, the team needed to converge on a design idea that was acceptable to Rocketdyne senior management's conservative perspective, since it was senior management who needed to approve the design for formal testing.

SLICE Team: The Success Story

Despite these challenges, the team was a run-away success. The team successfully designed a thrust chamber for a rocket engine made of six parts instead of the normal ~1,200 (a 200-fold decrease in part count), a manufacturing cost reduction from $7 million to $0.5 million (a 14-fold decrease), and a predicted quality level of 9 sigma, meaning less than one failure out of 10 billion, instead of the current industry best-practice of 6 sigma and more conventional 2 to 4 sigma for rocket engine combustion devices. In addition, the normal first unit production cost of $4.5 million was reduced to $47,000. The team was able to achieve all of this with no member serving more than 15% of their time, within budget, within 10 months instead of six years, with more than a 50% reduction in total engineering hours compared to traditional teams. On the basis of a formal end-of-the-project technical review by the seven senior technical managers, the project was judged as successfully achieving its objectives. The managers approved the design for the next step in the development process: a cold-flow test assessing the validity of the analytic assumptions of liquid flow through the parts.

Fortunately, we were able to closely trace the lifecycle of the team using several data collection methods: ethnographic observation, panel questionnaire surveys, interviews, "lessons learned" group meetings, and weekly logs of collaborative technology usage. One of the study authors became a participant observer in the team's process, attending all 89 virtual meetings and analyzing all 651 entries in the Collaborative Technology referred to as the "Internet Notebook" (using the metaphor of an Engineer's Notebook) and a Project Vault (for the files unlikely to change). The entries included requirements, major models and analyses, budgets and schedules, as well as briefing charts and other documents, creating a single source of product and process data. The log of the activity of the team members in using the Notebook and the Vault were examined to determine which functions of the technology team members used. Finally, a lessons-learned session was conducted with senior managers of the project.

Patterns across these data were investigated to identify those management practices that seemed to contribute to the success of the team. We found three such practices were needed in order for this VC^3 team to succeed:

(1) **Strategy-Setting**: Establishing an umbrella agreement in advance of team formation

(2) **Technology Use**: Using collaborative technology not only to collaborate but also to manage knowledge

(3) **Work Restructuring**: Restructure work processes without changing the core creative needs of the team

We elaborate each of these management practices, using examples from our case to illustrate our points.

Management Practice 1: Strategy-Setting—Establish A Virtual Teaming Umbrella Agreement Preceding the Creative Team Project

Prior to the SLICE team, even prior to the conceptualization of the SLICE team, senior managers, contract managers, and program managers at the three companies engaged in a series of discussions and negotiations. The three companies were identified through a series of discussions in which best practices were shared and the skills of employees were discussed. These discussions took about a year and focused on identifying the complementary skills that each partner company could bring to a creative design process if one became needed, the compelling business reasons for each company to share their resources and the skills and knowledge of their employees in a cooperative venture, and solutions for handling the risks associated with such a cooperative venture. Resulting from these meetings was a fairly simple written agreement between the top managers at each company, referred to as the "Continuous Ordering Agreement." This written agreement defined the contractual obligations the companies entered into on how intellectual property would be defined and allocated, how company confidential information would be protected, how liability would be allocated, etc. Importantly, the agreement specified the level of participation of member companies to a virtual team, ensuring that one company would not dominate the process, nor reap the majority of the rewards. This umbrella agreement did not refer to a particular project or task order, but was instead intended to cover specific task orders when a particular business opportunity arose to warrant the companies teaming on a particular project.

Umbrella Agreement Comes In Handy

One of the companies suffered significant management upheaval during the course of the project and the team members from that organization were pressured to renege on their commitment to be engaged in the design effort. The agreement of equal participation in the effort, however, prevented management from pulling the team members. Thus, the management practice the team found critical to its success was the creation of an umbrella agreement between firms that resolved issues of core competencies, contribution to team efforts, stability of team membership, and open information-sharing before the team was formed so that the team could progress in a supportive context.

To have had senior managers at each company sign this written agreement required many additional non-written agreements. These agreements had as much to do with trust and understanding between similar-level managers at the partner companies as it had to do with the specifics of how the agreement would be implemented within each company. A critical part of creating the trust involved clearly defining how the risks were to be managed in each company. For example, one senior manager would only agree once he was convinced that the senior managers at the other companies perceived each company's core competency in a design effort in complementary and non-competitive ways. A senior manager at another company was quite concerned about the use of his engineers on design projects not currently part of his organization's product portfolio and showed no interest in teaming until he was convinced that the arrangement would broaden his company's product portfolio in strategically meaningful ways. Another part of creating the trust was working out how project responsibilities would be handled. Typically, project activities and budgets are subdivided between organizations, having the effect of organizations focusing exclusively on their own deliverables and budget. In addition, the agreement called for the creation of only a team statement of work when the time for a specific statement of work was required. The team statement of work would not decompose the task into tasks specific to each company. Moreover, there would be only one team budget without breakouts for either companies or individuals. This type of an agreement forced the responsibility and associated budget for the entire team effort to be allocated to all team members and allowed them the discretion to reallocate resources as needed across organizational boundaries. Every activity, therefore, was placed in the context of the total project scope and budget.

Having the Continuous Ordering Agreement in place proved critical to the success of the team. First, since it covered intellectual property and confidentiality arrangements, the engineers on the team reported that they could openly share information since they did not have to worry about management's concerns about sharing information. Second, having the agreement in place meant that, when the business opportunity for SLICE did arise and a purchasing agreement with a statement of work needed to be generated and approved before work could start, the elapsed time from idea to project kick-off was dramatically reduced (from months to days). Finally, having the agreement in place protected the team from management changes (see the box: Umbrella Agreement Comes in Handy).

Management Practice 2: Collaborative Technologies are Knowledge Management Technologies

The team's collaborative technology—the Internet Notebook and the Project Vault—were explicitly developed by a third party in response to a list of requirements specified by several team members. The notebook technology allowed members to securely access it from anywhere; to create, comment on, reference-link, search, and sort entries that could consist of sketches, snapshots, hotlinks to desktop applications, texts or templates; and an electronic white board that allowed

Technology Enabler: Coordination Protocol

- Use a pre-specified list of keywords (three keywords to describe each entry) in order to facilitate ease of finding entries later on.
- Receive training on the use of the Notebook before starting design work so time during meetings would not be spent in training.
- Create reference links for each entry that was derived from or built on other entries in order to facilitate later recall of the history of entries.
- Create and use notification profiles so that each person would be informed when new entries were created that were of a type they had chosen to be relevant.
- Use templates for agendas, minutes of meetings, action items, and decisions so that a standardized search would yield relevant information.
- Take time before meetings to enter comments on others' entries (to encourage the asynchronous work on the project and appropriate preparation for meetings).
- Create new entries when changes to existing entries are needed so that a train of thought could be observed and the original author could preserve his ideas.
- Copy and paste important entries into the Document Vault for configuration control.
- Conduct meetings as electronic meetings (everyone logging into the Notebook at the same time and viewing and revising the same entry) supplemented with audio (as teleconferencing when needed) with everyone's complete attention devoted to the meeting.
- Use the Notebook for all communication and knowledge-sharing needs (including, for example e-mail and file sharing).
- Use the navigation search capabilities to find needed information quickly.

for near-instantaneous access to the same entry (see Figure 1). Thus, from the outset, the team had the advantage of having a technology explicitly suited to their initially defined needs. The team focused their early discussions on creating a coordination protocol for facilitating its collaborative use (see the box: Technology Enabler: Coordination Protocol). The Project Vault allowed secure common file storage and transfer for these files, both large and small, on an as-needed basis. These capabilities thus created the immediately accessible single source of both product and process data for all enterprise-wide activities associated with the project.

The protocol the team developed made team members change the way they normally worked with other engineers in fundamental ways: from face-to-face discussions to complete reliance on technology for collaboration, from sharing information on a need-to-know basis to sharing all information with everyone on the team all the time, from using personal collaborative tools (e.g., different e-mail applications across the companies) to using a single one. Initially, then, with this coordination protocol, the team made a statement that said: *all information will be entered into the notebook and shared among all members all the time*.

Over time, this protocol needed to be modified in critical ways. Most of the modifications came not because collaboration was difficult using the technology but because the management of the knowledge became difficult. One such example of this need to develop new norms for managing knowledge occurred very early in the project. The team quickly discovered that there was too much information being generated to be captured and that much of the information was likely to have only transient utility (e.g., as new designs are generated, old designs, discussions, and analyses are of limited value); thus, their expectations that they would document everything was just too cumbersome. To manage the overwhelming amount of knowledge needing to be conveyed, the team learned to couple written documentation (as entries) with oral communication. That is, the project team leader began to call for twice-weekly brainstorming sessions using teleconferencing coupled with the Internet Notebook (eventually yielding 86 "virtual meetings" in total or about 2.5 per week). In preparation for each meeting, team members would post incomplete entries, which would then be the source of much discussion during the teleconference. Thus, ultimately, the team followed the protocol by sharing all knowledge with everyone—but only because everyone was required to be on the teleconference and logged into the network and view documents.

Another example of the team needing to modify its coordination protocol to accommodate knowledge management issues was the initial total reliance on the collaborative technology; i.e., the prohibition of face-to-face discussions on the project when chance encounters between project members occurred, as they occasionally occurred when some members saw each other at another meeting or in the company cafeteria. Three weeks into the project, one member of the team let slip in a teleconference that he had had a face-to-face conversation with another team member; the remaining team members indicated that this was against the coordination protocol and much discussion ensued. In the end, the team agreed that the issue was not one of enforcing a rule that prohibited face-to-face conversations but to ensure that knowledge gained during face-to-face meetings was shared with all. All team members, therefore, agreed to create entries that would briefly describe the results of face-to-face meetings from this point forward. This was critical to maintaining a feeling of "equality" among team members.

Yet a third example of the team modifying its coordination protocol to accommodate the complex knowledge management issues was the protocol that insisted that team members would devote their exclusive attention at all virtual meetings. The team quickly learned that collocated workers on other teams from their parent company often interrupted busy team members during lengthy teleconferences to ask questions. Initially, team members negatively viewed these interruptions and a team member's willingness to succumb to these interruptions, even temporarily, during a teleconference. However, over time, the team began to realize that the issue was not having the team member's complete attention during a teleconference (since, often times, highly specific issues were discussed that did not have immediate consequence to all members), but rather having the team member's knowledge immediately available during a teleconference when needed. Thus, a team member might be answering a question from someone at the parent company, but then return to the teleconference when the project leader called, "Dick, we need you now; please return." Thus, the coordination norms shifted from providing complete attention to "just-in-time knowledge-sharing." This acceptance of just-in-time knowledge sharing had an additional benefit. Since team members were located in their own offices with their own powerful desktop tools, and given "permission" to perform multiple tasks simultaneously, team members began to use their powerful desktop analysis packages to analyze designs during meetings. This is an activity that would normally have been conducted "off-line" and it would have taken days to get everyone back into a room to discuss the results. Instead, doing just-in-time analysis provided immediate feedback about the feasibility of a design idea, saving the team weeks in the design process (see the box: Just-in-Time Analysis). Extension of these ideas led to a redefinition of the concept of a meeting, from conventional meetings via telephone to meetings as work time where all tools and skills are with you in the "meeting."

Just-in-Time Analysis

In one distinct illustration, the combustion analyst sketched an idea into the Notebook during a teleconference—an idea that required a certain number of holes to be drilled into a metal plate. As debate raged about the number of holes, the CAD engineer used his desktop CAD tools to create a more detailed CAD drawing of the sketch and then analyzed it. He discovered during the teleconference that the drawing required more holes than there was room for! The combustion analyst was immediately convinced of the problem with his idea. The team then brainstormed solutions to this problem, yielding a new sketch. This capability to answer questions analytically from the desktop during meetings greatly sped up the design process

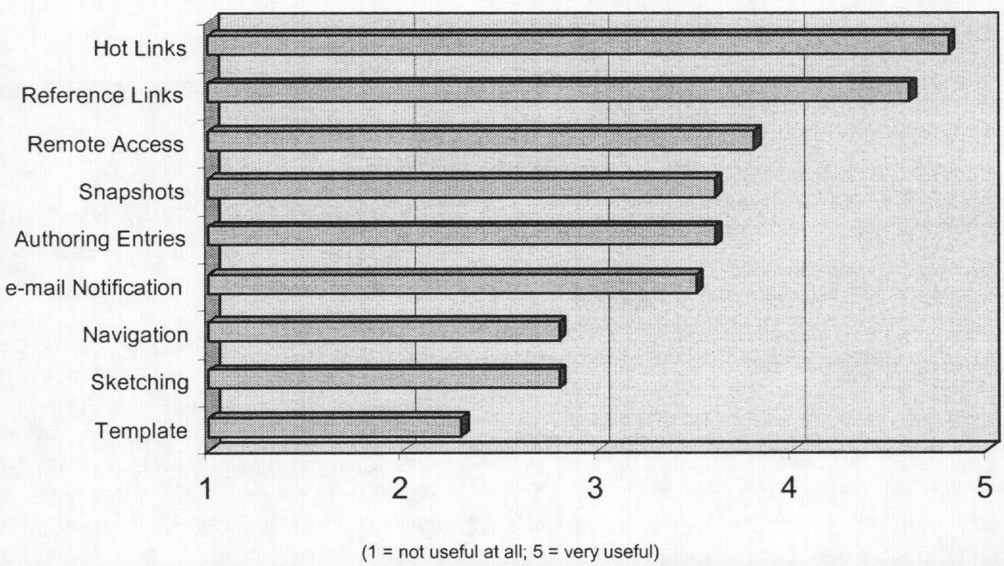

Figure 2. Ratings of SLICE Members at Project End on Usefulness of Notebook Features for Information Retrieval

Yet, even though the team eventually had over 1,000 entries to search in the Notebook, and even though searching occasionally took 10 minutes of a 45 minute teleconference (see the box: Knowledge Retrieval Is Hard), the team never found it desirable to use reference linking, multiple keywords, and more than rudimentary search capabilities (by a first keyword or the date). For example, only 37% of the entries had two or more keywords (not the three stipulated in the Protocol).

Why did the team profess to be interested in sophisticated knowledge management (i.e., knowledge capture and retrieval) capabilities but rarely use them? Upon further inspection, the reasons became clear: the team was generating so many new ideas (20 conceptually distinct design ideas were generated and evaluated) in such quick iterations that most of the knowledge in the repository was obsolete, and that which was not obsolete could be reasonably easily remem-

Knowledge Retrieval Is Hard

Lead Engineer: *"LK and I have just started to talk about how to treat the annulus. They are in the famous HB/LK entry; the one describing the sketch. Which one was that, HB?"*

HB: *"I forgot."*

Producibility Engineer: *"Could it be 905?"*

Lead Engineer: *"No."*

Producibility Engineer, looking at another entry: *"On the manifold, do you want to cast that flange on it? I thought [another team member] had a better idea. But which entry was that?"*

Other team member: *"I don't remember which one."*

Producibility Engineer: *"Is it #867 since that was the last PRO-E model we had?"*

Other team member: *"I think it's 915; no, maybe 911."*

bered and found by someone on the team, when needed. In other words, the tool did not (and could not) have a functionality to automatically determine when something was obsolete, and no one on the team was interested in "cleaning up" after a design idea was discarded. It is not just that the task of attaching keywords can be onerous for the team members whose primary role is to creatively conceptualize new products. Even if they tried to classify the entries according to keywords, very soon they found that information was changing too rapidly for them to gauge the nature of entries, let alone classify them based on keywords (see the box: Changing Information Makes Keywords Obsolete).

Our conclusion for management practices, then, is that the key to designing collaborative technologies for VC^3 teams is to recognize that it is a collaborative knowledge management system that is, in reality, being designed and used. Thus, capabilities should be designed to facilitate knowledge management, and norms to encourage knowledge sharing and reuse should be identified. We believe that knowledge management even with a good collaborative tool is a very messy process and this team benefitted from "far-from-perfect" practices.

Management Practice 3: Restructure Work Without Changing Core Creative Needs

In the beginning, the team thought it essential to completely restructure every work process it used in order to adjust to the virtual teaming mode: from the engineering tools to how decisions were made, from how meetings were run to how design ideas were generated. Over time, however, the team learned that while work processes needed to be restructured to accommodate the virtual nature of the collaboration, restructuring should not affect the basic creative needs of the team. The team learned that its ability to be creative rested on having three requirements met:

- a shared understanding of the problem, possible solutions, analysis methods, and language,
- frequent interaction with all team members in order to share work-in-progress, brainstorm ideas, and test out solutions, and
- rapid creation of information that is highly context-specific (i.e., specific to a particular conversation or problem) and then equally rapid discarding of information.

Changing Information Makes Keywords Obsolete

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."*

Another member 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."*

Creative Need 1: Create a Shared Understanding

To create a shared understanding within a creative team, the team initially adopted the common practice found in their best-practice design teams of centralizing the process around the lead engineer, who determined what needed to be shared about what. The concept behind "heavyweight" lead engineers is that they listen to different ideas from the different specialists and then offer new design solutions that meld the different perspectives. Because of their best-practice experiences, the team members encouraged the lead engineer to take a centralized role in the coordination of information.

Despite initially agreeing on a centralized role for the lead engineer, team members quickly found that, since a single repository was being used to hold all the information, team members became knowledgeable not just about the information the lead engineer wanted to discuss with them, but about all the information concerning the project that had been entered. This meant that team members were commenting on all aspects of the design, not just the aspect that was aligned with their discipline or the aspect that the lead engineer was interested in discussing with them. Individual team members reported that they found this enhanced participation to allow them to be more productive as well as lead to a more exciting involvement in the project. While the lead engineer at first chafed at this change, he eventually accepted the less centralized role. However, for all members of the team to fully participate in all aspects of the design, the team found it necessary to develop a common language for brainstorming. Efforts to use discipline-specific or product-specific language failed since members were not all equally versed in each other's discipline or product. Instead, what worked was the use of "common-language" metaphors (see the box: Metaphors Create a Common Language).

Without shared artifacts, shared understanding suffers. To accelerate the development of shared understanding, then, managers of VC^3 teams need to help the team create shared artifacts quickly. One way the team did this early on was the creation of an entry in the Notebook that contained an empty matrix listing the 12 designs generated to that point. Each team member was requested to evaluate each design for its likelihood of meeting the functional requirements of each analyst's area of expertise and to insert the results of this evaluation into the matrix. The team obliged and found the process enormously valuable—not for the outcome (the design receiving the highest evaluation was eventually discarded) but for the shared understanding about the design process that the matrix created. In the words of one team member, *"With that entry, I felt we were a team and we knew our role on that team."*

Creative Need 2: Engage in Frequent Interaction

In collocated teams, team members frequently report that some of the best discussions occur spontaneously, based on frequent interactions with collocated workers. Carrying this into the team's virtual environment, team members expressed concern that one-on-one conversations would harm the team since it could lead to members feeling left out, or feeling inadequately briefed about information critical to their performance on the team (see the box: Guarding Against Alienation).

Metaphors Create a Common Language

Stress tests indicated that the proposed injector would not be strong enough to survive lift-off. The team members struggled with various ways to increase the strength, spending some time trying to "point" out various places where the design could be reinforced. Nothing captured the imagination and consensus until one of the team members suggested that the team add reinforcement to the middle, *"like an agitator in a washing machine."* That simple metaphor was immediately understood, accepted and used as the basis for redesign.

Guarding Against Alienation

In the words of one team member: *"It is very important to me to not feel left out. If I'm not there* [meaning not physically collocated at Rocketdyne], *I want to know I'm not missing anything."*

Incomplete Entries as Catalyst for Knowledge Generation

Halfway through the project, a new combustion analyst joined the team. One of the analyst's first entries was a design concept that had an inaccurate parameter. When one of the team members identified the inaccuracy in a meeting, the analyst simply wrote a comment on his entry by crossing out the inaccurate number and replacing it with the right one, rather than feeling the need to create a new entry with the correct number. This simple act of the analyst changed the dynamics of the team; after that point, the team members began putting more entries into the repository that were less formal (e.g., spelling errors, for example), and with comments indicating corrections.

Thus the team replaced one-on-one conversations with frequent all-team conversations. The team also handled this frequency of interaction issue by broadening out the definition of interaction to include posting of entries to the knowledge base; team members who reviewed postings were virtually interacting with members. To facilitate frequent posting and review of entries, the team leader forced the use of the Internet Notebook for all file-sharing and information-sharing; for example, project management plans, status reports, budgets and cost sheets, meeting agendas, meeting announcements, and meeting minutes were all posted exclusively through the Notebook. In addition, initially the members were reluctant to post entries in the repository because they had the impression that entries should be complete before posting; in the words of one team member, *"this repository might be subpoenaed in the future if there is an accident on the launch pad."* Over time, however, team members became less concerned about the completeness of entries and more concerned about sharing entries. In fact, incomplete/inaccurate entries became seen as a source for healthy discussion, which in turn led to new knowledge creation (see the box: Incomplete Entries as Catalyst for Knowledge Generation). Ultimately, the continuous sharing and documentation of work in progress was one of the biggest shifts from the norm for the engineers. Instead of each "engineer" accepting a work assignment, working it to its end, assuring its correctness, and preparing a pretty method to present his results to the rest of the team, team members presented their ideas and sketches, relying on past experience and expert judgment. The more detailed analysis followed when ideas stabilized.

Creative Need 3: Rapidly Create Context-Specific Knowledge

Twenty designs were generated in the course of the 40-week project, with most designs having less than one week of life before being discarded. To rapidly create designs, team members from the different disciplines would come to each teleconference with design sketches that would have been entered immediately prior to the meeting; then, during the meeting, team members would modify the sketches using the electronic drawing board capability while explaining the reasons for the change and how the change was intended to affect the design parameters. The team found that drawing sketches by hand during meetings was too time-consuming and thus modifying existing drawings was much more efficient. In addition, the team also came to realize that sketches could not contain all the information necessary (because no member wanted to spend the time to refine or elaborate the sketch for communication to others). Thus, the highly context-specific knowledge of the design (e.g., "this sketch presumes that we use X type of material" or "this sketch assumes that the fluid will flow in the following manner after take-off") were saved for the teleconferences when each sketch was discussed and redesigned. Team members felt that this process encouraged members to enter sketches, albeit incomplete ones, and allowed members to focus their discussions on the assumptions of the design as they were made explicit in the conversations.

Summary of How to Restructure Work with VC^3 Teams

Table 2 summarizes the way the SLICE team managed their core needs, comparing these practices to those often used in collocated teams or virtual teams where concept development is done in a collocated fashion. In sum, then, we found that the team was able to function successfully because it changed its work processes to meet its core needs. That is, the core needs of creative teams do not change just because the team becomes virtual and inter-organizational; how these needs are achieved, however, will change.

Not only were new practices needed in setting the strategy through an umbrella agreement, in designing technology that evolved with the team's needs, and in identifying work processes that facilitated the creative effort, we found that effort devoted to each practice area—strategy, technology, and work—was different over the life span of the project. The team found that strategy practices needed to be put into place before either the work or technology practices were initiated.

In addition, the team found that their dependence on the technology and coordination protocol (albeit one that eventually changed) required that the technology needed to be in place before the team's work process started. In fact, the team start was delayed several times while the technology was being debugged. Once the technology was in place, however, the team learned that it needed the ability to modify the technology as its work processes were adapted. In fact, 23 versions of the technology were created during the course of the project, in large part the result of complaints lodged by team members to the technology developer. As a result, a technology facilitator was required to attend all teleconferences so that problems could be fixed immediately (such as someone not understanding how to perform a particular operation, or a server going down and rerouting or notification was needed, or a team member using an old version of the technology). Finally, throughout the project, the team needed to devote effort to its work practices since many of the initial practices did not work once the project got underway. Figure 3 depicts the differential effort required in these three areas of technology, strategy, and work practices over the course of the project.

Implications for Practice

Whether the objective be tactical in nature (i.e., reduction in costs and time, increase in quality) or strategic (i.e., increased flexibility, creation of new knowledge competencies), VC^3 teams will increasingly be favored in the search for orate renewal through shared destiny with other organizations. It is very likely that global and knowledge-intensive competition will make it imperative to pool the intellectual capital of employees across

Table 2. Structuring Core Processes for VC³ Teams

Core Needs of Creative Teams	Practices of Collocated Creative Teams	Practices Adopted by VC³ Teams
Development of shared understanding	• Lead engineer is "spoke-in-the-wheel" for coordinating information and consolidating ideas into new design proposals, which constitute the shared understandings of the team.	• From spoke-in-the-wheel coordination (with lead manager/engineer in center) to democratic coordination • Encourage development and use of "common-language" metaphors
Frequent opportunities for interaction with team members	• Collocation allows for frequent and spontaneous interaction.	• Coupling use of knowledge repository with synchronous and frequent teleconferences • Allowing for one-on-one discussions when need arises but documenting results for everyone
Rapid creation and sharing of context-specific transient information	• Most discussion verbal and undocumented, hard to capture the context.	• Promote only minimal cataloging of new information—even to the extent of restricting it to "touchstones" and "placeholders" • Timely and frequent discussions of new entries in knowledge repository to enable members to learn the context

Early Warning Signs

- Team not being able to initiate their creative task—bogged down in seeking administrative clearances.
- The collaborative tool not being utilized by team members for the creative task entrusted to them.
- Expression of dissatisfaction with processes by team members in early stages.
- Team process hits a dead end and new ideas not being floated or discussed.
- Sparse knowledge entry into the repository of the collaborative tool.
- Entries are being made into the repository but log files show that team members are not calling up entries.

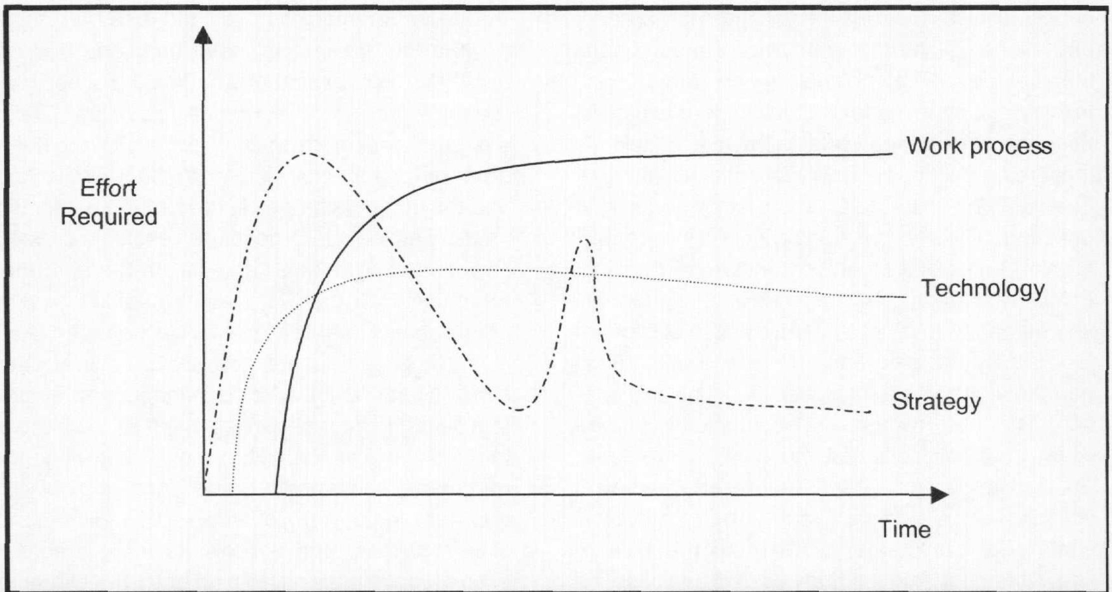

Figure 3. Effort Distribution Across Team's Lifecycle

organizations and geographical distances, and that increasing time demands are making it difficult to do so through the traditional mode of face-to-face collocated teams. Organizations are turning to VC^3 teams to solve this paradox. Although every VC^3 team will take on a life of its own, there are some early warning signals that, if paid heed to, can ensure the success of the team (See the box: Early Warning Signs).

The success of such teams will require not just provision of technology but more importantly formulation of appropriate inter-organizational strategy and structuring of conducive inter-organizational work processes and dramatic reassessments of current business contracts, practices and processes. Further, all three—technology, strategy and work processes— will have to be flexible enough to be molded to the requirements of each of these teams depending on their creative requirements.

Implications for Research

As with any case analysis, the generalizability of the results can only be assessed by observing future similar cases and by applying theory to understand the behavior patterns. Thus, the first implication of this study for future research is to encourage researchers of virtual teams to examine virtual teams varying in level of innovativeness. If these findings are supported in future research, they suggest that an important factor determining how knowledge is shared in virtual teams is the innovativeness of the team objectives: highly innovative teams are innovating in both process and product and thus their knowledge-sharing practices are likely to evolve over time. Identifying patterns in this evolution across cases will be an important first step toward creating a theory of knowledge-sharing in virtual teams.

This study offers another implication for research. As recently as 1999, DeSanctis and Monge reported that the literature suggests that "some tasks are performed less effectively when done electronically; for example: consensus formation" (p. 696). Later in their article, they state: "About the only consistent finding in the empirical literature with regard to task and media is that [the tasks of] thinking convergently, resolving conflict, or reaching consensus [are] better done face-to-face than electronically" (p. 697). Finally, they conclude: "exchanges involving knowledge-elicitation or sharing may more readily lend themselves to the virtual mode than those involving consensus formation....There is a great need for research that isolates the task conditions that are most effective in virtual settings" (p. 697). The SLICE case calls such statements into question. Clearly, the eight engineers were performing tasks that involved convergent thinking, conflict resolution, and consensus development—and managed to do so without the use of face-to-face. Why the difference between our findings and those in the extant literature? One explanation might be provided by DeSanctis and Monge when they point out that much of the research results described in the literature are based on studies of electronic mail and computer-conferencing systems, rather than the type of knowledge portal technology used in this case, as well as communications that use multiple media. In electronic mail, it may be harder to combine context and content, whereas combining portal technologies with voice allows for making authorship, documents, document histories, and team comments as well as context accessible to all participants simultaneously. Thus, one implication of this case is to suggest that task-media fit questions are not the right questions to ask at all—especially with highly innovative teams. In such teams, knowledge-sharing for purposes of informing others cannot be distinguished from consensus-building, since it is in the process of consensus-building that knowledge is shared, and vice versa. Thus, the research question is not one of predefining which tasks will work and won't work in virtual settings, but how tools, work processes, and group and organization structures can be designed to facilitate knowledge capture, dissemination, and synthesis under different task conditions.

Finally, the SLICE case clearly raised research questions about how to structure knowledge-management systems for radical innovation. The engineers never effectively resolved the issue despite working closely with the technology developer to produce 23 different technology versions during the 10 months of the team activity, and working closely with management to be permitted to make extraordinary modifications in the typical engineering work process. In the end, the team members never did use the tool's powerful navigation and search functionalities, nor did they ever document any but the most rudimentary context knowledge possible. For example, design rationale documents were never prepared; as a result, a team in the future will not find the 600-plus entries in the Notebook of much value. The team also never did resolve the issues of speedy knowledge retrieval. In the end, they recommended that VC^3 teams should consider establishing a role of a knowledge manager. Such a knowledge manager can serve several functions. First, the knowledge manager can ensure that valuable information is not left unrecorded in the knowledge repository by reviewing the roadmap of the repository and identifying obvious gaps in logic. For example, if explanations, circumstances, and constraints for quantitative estimates are missing from an entry (for example, the circumstances under which the impinging holes in a design would be too expensive), the knowledge manager could ask for more detail. Second, the knowledge manager can help to ensure that outsiders such as managers can review the entries in the information repository, by providing an easy way for others to get the information they need. Finally, the knowledge manager can ensure that the team is able to make use of the documentation that they create by reminding the team of past information and helping them find it when needed.

This problem of how to design knowledge management systems for innovation has been recognized by other scholars as well. Boland et al. (1994) and Malhotra (2000) attribute this problem to the simplistic representation of knowledge management that an information-processing view promotes—a representation that objectifies information, presupposes a one-for-one mapping between words in an information system and objects or conditions in the worlds, and overlooks the fact that words are symbols whose meanings are always multiple and ambiguous. An alternative representation of knowledge management could be one proposed by the distributed cognition literature (Hutchins 1991; Resnick 1991). In this view, knowledge is not "shared" per se, but rather individual actors create an understanding of knowledge by acting and observing how others act on this knowledge. A knowledge management system designed to support distributed cognition would need to go beyond the functionality of a searchable knowledge repository. In addition, the system would need to provide an editable whitespace for easily capturing new ideas and blending idea generation with selection (Olson and Olson 1996). It would also need to allow automatic categorization of the knowledge, so that users need not presuppose a keyword hierarchy or organization of the knowledge. Finally, it would need to support the simultaneous display of multiple representations of knowledge—representations that are distinctive for different individuals as well as varied in level of detail (Boland et al. 1994). While the technology used by the SLICE team had some of these features (an editable workspace), it did not have all of them. Future research is required to determine to what degree these additional features will help to alleviate the knowledge management problems the team encountered. Given the team's success, maybe technology for knowledge management is less important than technology that allows knowledgeable people to collaborate.

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