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RESEARCH ARTICLE

TECHNOLOGY ADAPTATION: THE CASE OF A COMPUTER-SUPPORTED INTER-ORGANIZATIONAL VIRTUAL TEAM[1]

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Abstract

The adaptation process for new technology is not yet well understood. This study analyzes how an inter-organizational virtual team, tasked with creating a highly innovative product over a 10 month period, adapted the use of a collaborative technology and successfully achieved its challenging objectives. The study of such a virtual team is especially useful for extending our understanding of the adaptation process as virtual teams have more malleable structures than typical organizational units and controlled group experiments. Data were obtained from observations of weekly virtual meetings, electronic log files, interviews, and weekly questionnaires administered to team members. We found that the team initially experienced significant misalignments among the pre-existing organizational environment, group, and technology structures. To resolve these misalignments, the team modified the organizational environment and group structures, leaving the technology structure intact. However, as the team proceeded, a series of events unfolded that

[1]Sirkka Jarvenpaa was the accepting senior editor for this paper.

caused the team to reevaluate and further modify its structures. This final set of modifications involved reverting back to the pre-existing organizational environment, while new technology and group structures emerged as different from both the pre-existing and the initial ones. A new model of the adaptation process—one that integrates these findings and those of several previous models—is proposed.

Keywords: CBCS, collaborative work systems, groups, problem solving, information attributes, longitudinal study, remote work, innovation

ISRL Categories: HA08, HA12, AA09, AC03, AD05, AI0113, BD103, DD05

Introduction

This study analyzes how an inter-organizational virtual team, tasked with creating a highly innovative product over a 10 month period, adapted the use of a collaborative technology and successfully achieved its challenging objectives. We were interested in understanding what adaptations occurred: Were they primarily with the technology, work group, or organizational environment? How often did these adaptations occur? What was the role of pre-existing structures in these adaptations? The study of a virtual team is especially useful for extending our understanding of the adaptation process as virtual teams have more malleable structures than typical organizational units and controlled group experiments. The paper proceeds by first extending structuration theory using the context of a virtual team, then describing our case study research methodology and results, and ending by discussing the theoretical and practical implications of the results.

Conceptual Development

In this section, we first summarize structuration theory and several models for explaining the adaptation process, identifying key differences between the models. Resolving these differences forms the basis for our research questions. We argue that virtual teams provide a "revelatory" case, where a researcher has an opportunity to study a previously inaccessible phenomenon, or at least, as of this time, a unique case (Yin 1994) in which to address our questions. We elaborate this point by introducing the virtual team we had the opportunity to study.

Structuration Theory Applied to Information Systems

Structuration theory, largely associated with Giddens' (1984) institutional theory of social evolution, has been used to explain organizational adoption of computing and information technologies (Barley 1986; Orlikowski 1992; Orlikowski and Robey 1991; Rice 1994; Rice and Gattiker 1999). Adaptive structuration theory extends structuration models to consider mutual influence of technology and social processes (DeSanctis and Poole 1994; Poole and DeSanctis 1990).

Structuration theory suggests that the implementation and use of new technology are not deterministic; technologies are structured by users in their contexts of use (Contractor and Eisenberg 1990; DeSanctis and Poole 1994; Johnson and Rice 1987; Orlikowski 1992; Orlikowski and Yates 1994; Poole and DeSanctis 1990; Rice and Gattiker 1999; Walsham 1993; Yates and Orlikowski 1992). The structuring of technologies in use refers to the processes through which users manipulate and reshape their technologies to accomplish work and the ways in which such action draw on the particular social contexts within which they work.

Based on research conducted from a structuration theory perspective, the technology adaptation process is now understood to be one that evolves over time—sometimes gradually, sometimes discontinuously—in response to interruptions (Tyre and Orlikowski 1994) or intentional management policy (Johnson and Rice 1987; Orlikowski et al. 1995), and is constrained by pre-existing structures (Barley 1986) of the organization and its associated tasks, technology, and the group (DeSanctis and Poole 1994). Thus, in

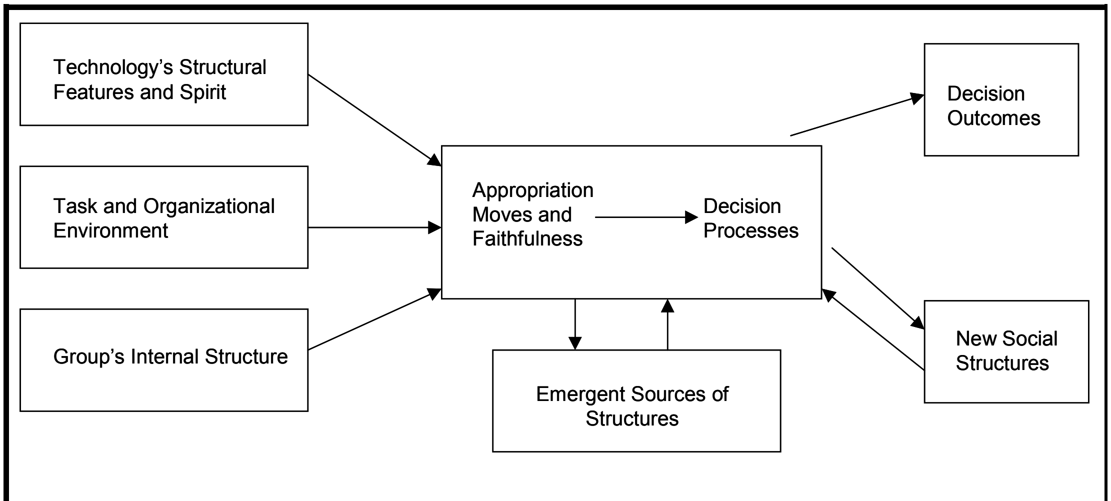

Figure 1. Summary of Adaptive Structuration Model (DeSanctis and Poole 1994)

the context of these pre-existing structures, new technology represents "occasions for restructuring," not determinants of particular outcomes.

There are several different models in the literature for describing how the adaptation process unfolds. Adaptive Structuration Theory, as described by DeSanctis and Poole, portrays the process by which technologies are adapted as consisting of structures, appropriations, and decision outcomes. As Figure 1 summarizes, their model describes three sources of structures as pre-existing conditions that form the context in which the technology is implemented and, as such, affect appropriations, which in turn affect decision processes and outcomes. *Technology* structures include the restrictiveness, sophistication, and comprehensiveness of its features as well as the technology's "spirit," the general intent of the technology with regard to values and goals. *Task and organizational environment* refers to the nature of the task (such as complexity and interdependence) and the organizational setting such as hierarchy, corporate information, and cultural beliefs. The *group*'s structure includes the interaction patterns and decision-making processes of its members.

Appropriations, which may be subtle and difficult to observe, are defined as the immediate, visible actions that evidence deeper structuration processes. Assessment of appropriation processes is at the heart of the Adaptive Structuration Theory framework, by documenting exactly how technology structures are being invoked for, or constrained in use in, a specific context. Appropriations can be analyzed for their faithfulness (the extent to which appropriations are in line with the technology's spirit), their instrumental uses, or the users' attitudes. One hypothesis proposed by DeSanctis and Poole is that the more faithful the appropriation—i.e., the more that appropriations align with the technology's initial intent—the more likely the team's decision processes will lead to successful outcomes.

Figure 2 summarizes Leonard-Barton's (1988) model of the (successful) adaptation process. Here, the technology adaptation process is seen as cycles of misalignments, followed by alignments, followed by more but smaller misalignments, gradually evolving to a state in which the technology, the delivery system and the performance criteria are aligned. In this model, such factors as initial unfaithfulness to a technology's spirit are less detrimental to outcomes than leaving misalignments unresolved. This role of misalignments is similar to Tyre and Orlikowski's notion of discrepant events in the technology adaptation process. They found that discrepant events might be helpful for a group as they may trigger technology adaptations that in the long run

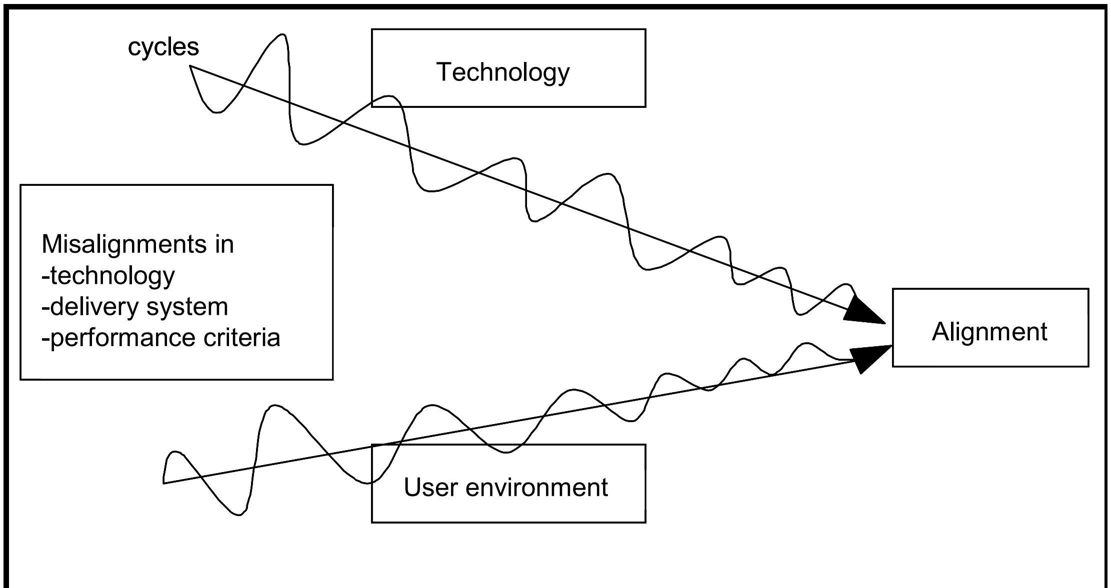

Figure 2. Summary of Misalignment Model (Leonard-Barton 1988)

make the technology more useful to the organization. However, the slope of adaptation, according to Tyre and Orlikowski, is not gradual, but initially steep with only brief windows of opportunity in which technologies could be modified. This role of discrepant events in triggering adaptations is similar to the process of reinvention proposed by Johnson and Rice, whereby the innovation choices are seen to be initially matched to (and often constrained by) prior adoption agendas, but may then be adapted in terms of use or form.

These various models of adaptation, therefore, all agree that adaptation is a process of modifying existing conditions in an effort to achieve alignment. The models disagree, however, on the nature of this adaptation. First, what is changed during the adaptation process to bring about alignment, according to both the Leonard-Barton and the Tyre and Orlikowski models, are *any and all* structures. In contrast, structuration theory (Giddens 1984) explicitly states that existing structures represent (varying) constraints on the adaptation process and thus are not necessarily all adapted equally. DeSanctis and Poole suggest that at least one structure—technology spirit—does not change during the adaptation process and poses a constraint on adaptation. Barley suggests a different structure—political and status differences—that poses a constraint on adaptation. We suggest that these differences between the models may be artifacts associated with the field research and controlled experimental settings that have had to examine technologies or political structures not amenable to change (such as information systems imposed on users). Thus, a theoretical conclusion that technology spirit or political and status differences are unlikely to change may be more a reflection of these limits on research designs than of theoretical conclusions about what can occur.

Empirically, it may be that a structure—any structure—can constrain an adaptation process not by virtue of what it is (e.g., technology, politics, status), but by the simple reality of it not being malleable, and that malleability may be so context-specific that *a priori* recommendations identifying particular structures as more or less constraining have the effect of inappropriately focusing attention on that particular structure. Thus, to resolve this difference between the models about whether any or only some structures constrain adaptation, one must examine a situation in which the structures are as malleable as possible to see which ones indeed change and which ones force other structures to adapt.

The models differ in another way as well: in the importance attributed to the degree or amount of misalignments. When DeSanctis and Poole say that "faithful" spirits lead to successful group outcomes, they imply that the fewer and smaller the adaptations, especially with regard to spirit, the more successful the outcome. In contrast, Tyre and Orlikowski propose that as long as misalignments can eventually be accommodated, the number or type of misalignments do not matter. The concept that "fewer is better" may be a reflection of a field study reality that often only permits few and small adaptations, or is focused on a large, transformative change, rather than a theoretical conclusion about what is likely to lead to success. Thus, examining a situation in which the structures are malleable both in the amount and degree of adaptation would permit addressing this difference between the models.

Finally, the models differ in the continuity presumed to occur in the adaptation process. Leonard-Barton's model proposes that adaptations occur continuously in response to misalignments, gradually leading to a successful alignment. In contrast, Tyre and Orlikowski characterize adaptation as a highly discontinuous process, where discontinuities occur during brief windows of opportunity which open the constraint set. This difference may reflect different conditions in the field rather than invariant theoretical conclusions. For example, adaptations may not be discontinuous by nature but reflect the field setting that Tyre and Orlikowski studied, i.e., one in which structures only became malleable at discontinuous intervals. Putting those same structures in a different field setting may have yielded a continuous adaptation process rather than a discontinuous one. Thus, the adaptation process may be neither inherently discontinuous nor continuous but rather responsive to changes in structural malleability, whenever that may occur.

Research Questions

The above differences in models suggest the need for further research on the adaptation process. The ideal research site would be one in which all structures would be as malleable as possible, yet occur in a real-world context so that external validity is maintained. In such a context, a workgroup that is permitted to modify its structures at the outset of a task allows us to address the difference in the models about which structures are malleable; a workgroup that is permitted to make both small and significant adaptations allows us to address the differences in the models about the amount and degree of adaptation; and a workgroup that is permitted to make changes throughout the process of task accomplishment allows us to address the differences in the models about continuous and discontinuous change. In such a setting, then, four research questions become salient:

(1) Can the workgroup adapt any or all structures, or does it primarily try to adapt to the technology's initial spirit?

(2) Do pre-existing structures constrain the workgroup's adaptation process, even when these structures are malleable?

(3) After the initial adaptation to achieve alignment, does the workgroup experience the need for further adaptations?

(4) What is the nature of these adaptations: are they discontinuous, responding to windows of opportunities, or are they continuous, gradually closing misalignments?

A Context for Minimizing Constraints of Existing Structures: A Virtual Team and Collaborative Technology

We had the opportunity to observe a newly constituted inter-organizational virtual team responsible for developing a revolutionary new product while adapting to a new collaborative technology. Virtual teams are defined as "groups of geographically and/or organizationally dispersed coworkers that are assembled using a combination of telecommunications and information technologies to accomplish an organizational task," which may be temporary and thus adaptive to organizational and environmental changes (Townsend et al. 1998, p.18). Because a virtual team spans multiple organizational contexts, the virtual team and sponsoring organizations are often more willing to experiment with new structures and thus offer an ideal opportunity to observe the results of malleability in their structures (Bowers 1995; Grudin 1994; Jarvenpaa and Leidner 1998; Townsend et al. 1998).

The team we studied, named SLICE (Simple, Low-cost, Innovative Concepts Engine), consisted of eight engineers from three different organizations: five from RocketCo, two from SigmaCo, and one from StressCo. The project was jointly funded by the three companies. Team members devoted 10 months, at about 15% of their time, to the project. The team members were selected to represent expert knowledge in a specific discipline related to the task; they had not worked together previously. Virtual team members were geographically distributed: two members were located in different ends of the same building, three other members were each one mile away in different buildings; one member of a second organization was located 100 miles away; and two members of the third organization were located 1,000 miles away in different buildings. SLICE members limited their travel since they were involved in many different teams within their company. As a result, all members were together only once—at the end—although there were three other formal meetings held in which some members attended and some informal conversations among members of one organization. The combination of geographic dispersion of team members, imposed disciplinary heterogeneity, different organizational affiliations, and lack of historical working relationships required the team to create structures for overcoming the challenge of sharing knowledge or simply understanding each other (Grudin 1994; Jarvenpaa and Ives 1994; Jarvenpaa and Leidner 1998; McKenney et al. 1992; Mohrman et al. 1995; Purser et al. 1992).

In addition to these common characteristics shared by virtual teams, the team we studied faced additional challenges not commonly encountered by a virtual team: it was tasked to develop (but not build) a concept and drawings for a revolutionary and highly complex rocket design that could be marketed by the three companies. RocketCo executive management, in charge of overseeing the technical quality of the work, recognized the revolutionary nature of the design task upon seeing the initial specifications for the new rocket design and voiced extreme skepticism that such a design could be created. Since product components were tightly coupled, team members from all three companies needed to work in highly interdependent iterative virtual brainstorming sessions, a structure with precedence for neither the team members nor the companies. In addition, inter-organizational collaboration for initial concept development is also unprecedented since new product development is considered a competitive advantage for each of these companies independently; other organizations are traditionally only included in development efforts after an initial concept is devised. The application of virtual teams to conceptualizing a new product added another layer of challenge and newness to the process. Recognizing the unique challenges faced by the team, management gave the team wide latitude to change structures. Thus the SLICE team provided an excellent opportunity to study a team with more opportunities for malleability than normal.

Virtual teams are made possible in large part due to rapid developments and diffusion of collaborative technologies (CTs). CTs include, at a minimum, a virtual workplace that provides a repository recording the process of the group, electronic information-sharing (such as through file sharing, e-mail, and electronic whiteboards), meta-information on the entries in the repository (such as date, sequence, and author of each contribution), and easy access and retrieval from the repository (Romano et al. 1998). As a result, such systems facilitate the access, creation, processing, storage, retrieval, distribution, and analysis of information across positional, physical, and temporal boundaries and allow the incorporation of members from other units and organizations with specific, otherwise difficult-to-obtain expertise (Lipnack and Stamps 1997; Warkentin et al. 1997).

The CT used for the SLICE project was called the "Internet Notebook" (www.nexprise.com). While the team members had experience with rudimentary CTs (e-mail, file transfer, video conferencing), the Notebook was seen as the first

Table 1. Features of the Internet Notebook

Characteristics of CTs	Features of the Internet Notebook
Interface	A custom-designed HTML browser that allowed members of the virtual team distributed access over a private network.
Different forms of interaction (such as e-mail and electronic white-boards)	The CT allowed the team members to simultaneously work on an entry together as a distributed team: to author new documents (called entries), comment on entries, and draw sketches as entries. This system was eventually complemented by using telephone conferencing along with synchronous system entries for synchronous, multi-media collaboration.
Shared information storage, access, and retrieval through meta-information (such as date, sequence, and author of each contribution to the repository)	The CT allowed team members to remotely access the Notebook from anywhere; to sort entries (such as by date, keywords, or reference links); to retrieve entries (such as by navigating or filtering entries by keyword, subject, date, or author as well as seeing the network of reference links to find frequently referenced entries for a particular topic). Team members could create a personal profile for e-mail notification of relevant entries and had a document vault in which documents requiring configuration control were entered.
A record of the process of the group	The CT allowed members creating new entries to make explicit reference links in an entry to prior entries; it had entries that contained summary of teleconference meetings, identifying action items and decisions made.
Libraries of solutions and practices	Team members could create and use templates for re-occurring team activities (such as minutes, agendas, and action items).

CT suitable for a complex engineering design collaboration because it supported multiple media types across multiple platforms for entering engineering content (i.e., graphical entries). The virtual team was asked to pilot the Notebook as part of their work effort. Table 1 lists specific features of the Notebook corresponding to the general characteristics of CTs noted above.

Research Methodology and Data Collection

Researchers have suggested that observations be made of the micro-processes of adaptation over time to determine which types of adaptation are more likely to lead to successful group outcomes (Barley 1986; Orlikowski and Gash 1994). In addition, such studies should not be limited to short time spans of technology use, as adaptations may occur over time. Finally, such studies should avoid obtaining data retrospectively, as this encourages respondents to gloss over details associated with variations in adaptation events over time or they may be biased by the same recently institutionalized practices and perceptions they are attempting to describe. Our data collection methods satisfy the above requirements and were geared toward understanding under what circumstances technological adaptations occur (Griffith 1999; Orlikowski and Gash 1994).

Case Study Methodology

Since emphasis was on understanding the process of the virtual team adapting the technology over its 10 month life span, a descriptive case study was used (Myers 1997; Walsham 1993). Case study is a well-accepted approach to study the complex phenomena of technology implementation in an organizational setting (Alavi and Carlson 1992; Orlikowski and Baroudi 1991; Yin 1994). In our data collection effort, we used interviews and documentary materials as the primary source of data (Myers 1997). We conducted private interviews with each of the eight members of the team at seven points in time: at the outset of the project to understand the existing and initial structures affecting the team; at 7, 14, 21, 28, and 35 week intervals to identify changes occurring at these times; and at a final meeting when a "lessons-learned" session was conducted. We also interviewed the seven RocketCo executive technical managers responsible for project oversight immediately after a mid-project review and again at the end of the project. We interviewed the Internet Notebook developer at several junctures during the team's work to determine his original intentions concerning the use of the technology and his reactions to how the technology was actually being used. In addition to the interviews, we also examined the entries created by the team in the Notebook to see how the CT was being appropriated.

We complemented the above methods with ethnographic data collection (Geertz 1973; Harvey and Myers 1995) in order to understand how the team's social and cultural structures evolved during the adaptation process (Lewis 1985). To do this, two of the study authors became observers in the team's process, listening in on all 89 audioconferences, reading all 1,000+ entries to the Notebook, and noting all uses of the Notebook during the teleconferences.

In addition to the teleconference notes, the first author attended all of the four in-person meetings that were held during the project. Not all of the team members attended all of the meetings (the kickoff meeting was attended by five out of the eight members, a mid-project technical design review by two members, a brainstorming session by four members, and a final technical review attended by all eight members). At each meeting, copious notes were taken of all conversations, including who said what, as well as additional social and non-verbal cues that were used (e.g., reference to a Notebook entry, hand gestures, eye-to-eye contact, etc.).

Several researchers have recommended triangulating qualitative methods with quantitative methods to ensure that the richness afforded by qualitative methods is supported by quantitative analysis (Gable 1994; Lee 1991; Markus 1994; Williams et al. 1988). Thus, we combined the rich note-taking of the observations, teleconferences, and interviews with a quantitative analysis of the CT entries as well as having team members complete a short weekly questionnaire. The questionnaire asked the percent of time on the project that members collaborated with each other that week (versus working alone on analysis) and the proportion of the collaboration time in which CT versus interpersonal (face-to-face or phone) media were used.

Finally, at the end of the project, the seven executives who attended the final technical review and were responsible for judging the outcome of the team's work, as well as the eight team members, were asked to complete a short questionnaire indicating the degree (on a 7-point scale) to which the team had effectively accomplished each of the team's work objectives.

Case Analysis Procedure

The analysis followed four steps. The first step involved reviewing the initial interviews to identify the pre-existing structures for each team member, i.e., how the team members would typically design a new product for their companies. We refer to these pre-existing structures as "Structures at T1." Structures were grouped according to the DeSanctis and Poole (1994) classification of technology, group, and organization environment. Since the essential nature of the task—new product development—did not change throughout the project, the task structure was not examined. According to DeSanctis and Poole, *technology* includes both the features and the spirit; spirit is defined as "the 'official line' which the technology presents to people regarding how to act when using the system, how to interpret its features, and how to fill in gaps in procedure which are not explicitly specified" (p. 126). *Group structures* examined included roles and actions of team members. *Organizational environment* is defined by DeSanctis and Poole as corporate information, cultural beliefs, and modes of conduct that influence how a team behaves. For the SLICE team, executive managers provided this environment by conveying and maintaining organizational culture, protecting the organization from risk, and preserving control in the face of an inherently unpredictable creative process.

The second step in the analysis was to identify appropriations and when they occurred. Appropriations made within the first few weeks of the project were referred to as “Appropriated Structures at T2"; those that occurred midway or later in the project were referred to as “Appropriated Structures at T3." Appropriations, equivalent to adaptations, are defined by DeSanctis and Poole as “immediate, visible actions that evidence deeper structuration processes” (p. 128), or more precisely, changes to structures. Appropriations were identified by reviewing the notes of teleconferences, in-person meetings, interviews, and the lessons-learned focus group meeting to find changes in structures. Changes in structure were then grouped together into similar appropriation topics. Eight specific topics were identified and grouped into four general topics:

1. Access to the communication tool (who gets access, when should they get access);

2. What knowledge is captured (what knowledge gets captured, how is knowledge captured);

3. What helps knowledge sharing (what is shared, what helps sharing); and

4. How are decisions made (who participates in what decisions, are technical requirements questioned).

For example, notes on a team member’s discussions about how to simplify navigating the growing number of entries in the Internet Notebook were labeled as the appropriation topic, “What helps knowledge sharing?” and grouped with discussion on which keywords to use when creating an entry. This labeling of notes as an appropriation topic was then corroborated by a review of the CT entries referenced during the discussion. For instance, when the team members discussed the need for accuracy in their entries during one teleconference (since outsiders would be reviewing the entries), the researchers checked the entries the team members had mentioned to determine how accuracy was manifested. In this example, we found that these entries had no dissension or comments that might question the validity of the results posted in the entry. Any interpretations made about CT entries were further corroborated by contacting the author of the CT entry to determine his intent. In sum, the appropriation topics were not theoretically deduced, but explicitly inductively derived. These topics, therefore, are not confirmation of a researcher’s *a priori* expectations of which appropriations would be made, but rather represent the appropriations that team members actually made.

In the third step of the analysis, we examined our notes to identify reasons why each change had occurred. For all reasons we were able to identify from our notes, we contacted individuals at the sites to discuss our reasons and to iterate until we obtained concurrence. The reasons were then reviewed to identify similar patterns.

In the fourth and final step of the analysis, we reviewed the outcome measures to assess the success of the adaptation process. We referred to the final manager survey, which rated the project on several outcome criteria, and obtained a summary statement of the project outcomes from a senior member of the executive review team. Table 2 summarizes the methodologies used for each analysis step.

Case Results

The results are organized by the analysis procedure: (1) pre-existing structures (Structures at T1); (2) misalignments and appropriated structures after the first few weeks of the project (Appropriated Structures at T2); (3) appropriated structures occurring after the midpoint of the project (Appropriated Structures at T3); (4) reasons for changes in structures; and (5) assessment of project outcomes.

Table 2. Timing, Nature, and Objectives of Methodologies Used		
Time	**Methodology Used**	**Use of Data in Analysis**
Start of the project	Private interviews with the eight members of the team, program manager, and CT developer	Identify structures at T1
Four in-person meetings, which some team members attended (kickoff, mid-project technical design review, brainstorming, and final technical review)	The first author attended the four in-person meetings and observed group processes, taking copious notes	Kickoff meeting used to identify structures at T1 Two mid-project meetings used to identify appropriated structures at T2 Final meeting used to identify appropriated structures at T3
At approximately seven-week intervals during the project	Two of the authors interviewed each of the eight team members and program manager	Identify reasons for appropriations
89 teleconferences during the 10 month life span of the project	Two of the study authors were observers in the team's process, attending all teleconferences (which were held with members in their distributed locations and lasted one hour each), listening in on conversations, observing members' use of the CT, and taking copious notes of the conversations and uses of the CT	Identify appropriated structures at T2 and T3 and reasons for appropriations
Weekly (43 weeks) during the 10 month life span of the project	The authors analyzed the actual entries into the CT made by team members A short weekly questionnaire was administered to team members	Identify appropriated structures at T2 and T3 and reasons for appropriations
End of the project	The first author facilitated a "lessons learned" focus group meeting with all team members plus private interviews with each team member and program manager. A questionnaire was administered to team members and their managers.	Determine outcomes of team

Result 1: What Was the Nature of Structures at T1?

The following narrative organizes the pre-existing structures by the DeSanctis and Poole (1994) classification of organizational environment, group structure, and technology. Space considerations permits us only to highlight the most critical details for understanding these structures.

Organizational Environment at T1

RocketCo is known as a leader in rocket design. The executive managers rose to the top of the organization because of their longevity with the organization and their technical ability to develop new products that not only out-performed the competition but avoided costly and life-threatening failures. The RocketCo project leader who funded this venture was able to convince RocketCo executive management to support this effort by providing documentation of the need for new products that met criteria that, in the past, had been thought unachievable, as well as documentation indicating that other organizations provided specialized expertise that RocketCo could benefit from during concept development. An agreement to become involved in the project, however, did not change executive management's basic risk-aversive nature. A requirement of no launch failures had established a proven but tacit process imposed by executive management of risk reduction through formal reviews and extensive analysis tied to test data. In addition, executive managers characterized themselves as "old style" engineers, preferring to "look an engineer in the eye before I'll believe him when he says his rocket won't blow up on the launch pad." Thus, in terms of our appropriation topics, the existing organizational environment was characterized by executive managers who made little use of electronic communication tools, preferring to discuss issues in face-to-face encounters; who saw their role as to identify and adhere to technical requirements for the design to avoid risk; and, as a result, who held to a very hierarchical notion of knowledge-sharing ("only those who need to know information should gain access to it and when they get information, I'll give it to them directly") and decision making ("we work with the project leader, not with the team").

Group Structure at T1

The typical group structure for new product development at all three organizations was to have a lead engineer and several specialists. The lead engineer provides specialists with parameters to analyze (e.g., to assess whether or not a material would hold up during initial take-off), and then privately integrate the individual analysis results provided by each specialist. As a result, a team's lead engineer made all of the decisions for the team and acted as a communication hub. The specialists rarely interacted with other specialists involved in the project, allowing the lead engineer to work out the conflicts in private. Consequently, there was no need for specialists to use common tools or even a common spatial geometry to share design models. The "big picture" need only be known to the lead engineer. As a result, the specialists rarely had the context to suggest beneficial changes to the overall product and, instead, focused their efforts on producing results that justified their positions in a rigorous formal review process to executive management. The specialists organized their results as graphs, with any assumptions, interpretations, and conclusions explained verbally. Changes to designs resulting from these analyses would then be made by the lead engineer on new drawing sketches. The lead engineer maintained a personal project binder, in which he would place any material he considered useful for the project. This typically meant that the binder contained calculations, finalized sketches, and key analysis results that might be needed to either justify the design or help identify causes if problems arose later. Few conversations were documented in these binders; typically, action items from occasional meetings of the entire project team were the only public information that was captured.

In sum, this existing group structure can be characterized as one in which specialists used their own tools; the lead engineer did most of the documentation but only in private notebooks and mostly just drawings and minutes; the lead engineer would share knowledge with others on a need-to-know basis; and team members functioned with a hierarchical management structure, submitting ideas and analyses to a lead engineer, who then reported these results to executive management.

Technology at T1

To coordinate their work, teams were familiar with a variety of technologies, ranging from e-mail and shared files (FTP servers) to videoconferencing and NetMeeting. Managers from all three organizations had experienced significant problems with each of these technologies and looked forward to having the opportunity to use the Internet Notebook. The intention of the Internet Notebook's developer (a former design engineer at Lockheed's Skunkworks), and an intention that was supported and encouraged by team members at the three organizations, was nothing short of what we will call "ubiquitous computing." The concept was that engineers would now be able to post all analyses, drawings, conversations, schedules, meeting minutes, action items, technical requirements, assumptions, design rationale, decisions, and presentations in a common repository for easy access and retrieval; that this repository would help the team not only keep track of its own process but be able to review its progress over time; and that the team would be able to do all this without the time often wasted in finding people, having face-to-face meetings, or waiting until the next day to get work done. By making the Notebook repository accessible to all those on the team from anywhere in the world, the team could eliminate travel to meetings as well as waiting to discuss issues by phone or in-person. Moreover, if all the information about the project was in the Notebook, there was little need to wait for formal meetings to apprise executive management of the team's progress; instead, executive management could be given access to the repository and encouraged to check out the team's progress on a frequent basis and provide comments at will.

In sum, this spirit of the technology could be summarized as: everyone (team members and managers alike) will use the system asynchronously, everyone will participate in capturing their own knowledge, all knowledge will be captured and shared continuously, and the powerful search features of the tool will enable everyone to do their own searches instead of waiting on others to find information. It was not the intent of the developer, managers, or team members that the decision-making structure be changed by the tool; as a result, there were no decision making aides such as voting or anonymity.

Result 2: What Was the Nature of Initial Misalignments with New Technology and Appropriations at T2?

Figure 3 presents a summary of the pre-existing structures at T1, with organizational environment in the outer circular, group structure in the next circular, and the structure for the new technology in the next most inner circular. The figure also indicates whether the organizational environment and group structures at T1 were initially misaligned with the new technology (those with an asterisk indicate misalignment). Finally, the figure shows the appropriations made at T2 (at the beginning of project) that were required to resolve these misalignments by organizing them according to the eight appropriate topics identified in the analysis and labeling them in brackets.

Apparent from the asterisks in Figure 3, the Internet Notebook's spirit created several misalignments with the pre-existing organizational environment and group structure. Examining the appropriations identified in brackets in Figure 3 and elaborated in the more detailed discussion below is the finding that, for all misalignments, the team and executive management initially accepted appropriations that deferred to the technology's spirit. That is, they viewed the spirit of ubiquitous computing to be so compelling that they were willing to make all necessary adjustments in their typical mode of operation to make it happen.

These appropriations were not imposed on them; instead, each team member and each manager made the decision personally and individually, agreeing that the futuristic spirit offered by the technology portrayed a work environment much more productive than the current one in which they worked. In what follows, these appropriations are briefly described.

Appropriated Organizational Environment at T2

The most obvious misalignment between the organizational environment and technology at T1 was the expectation that management would use the tool to communicate with the team, an expec-

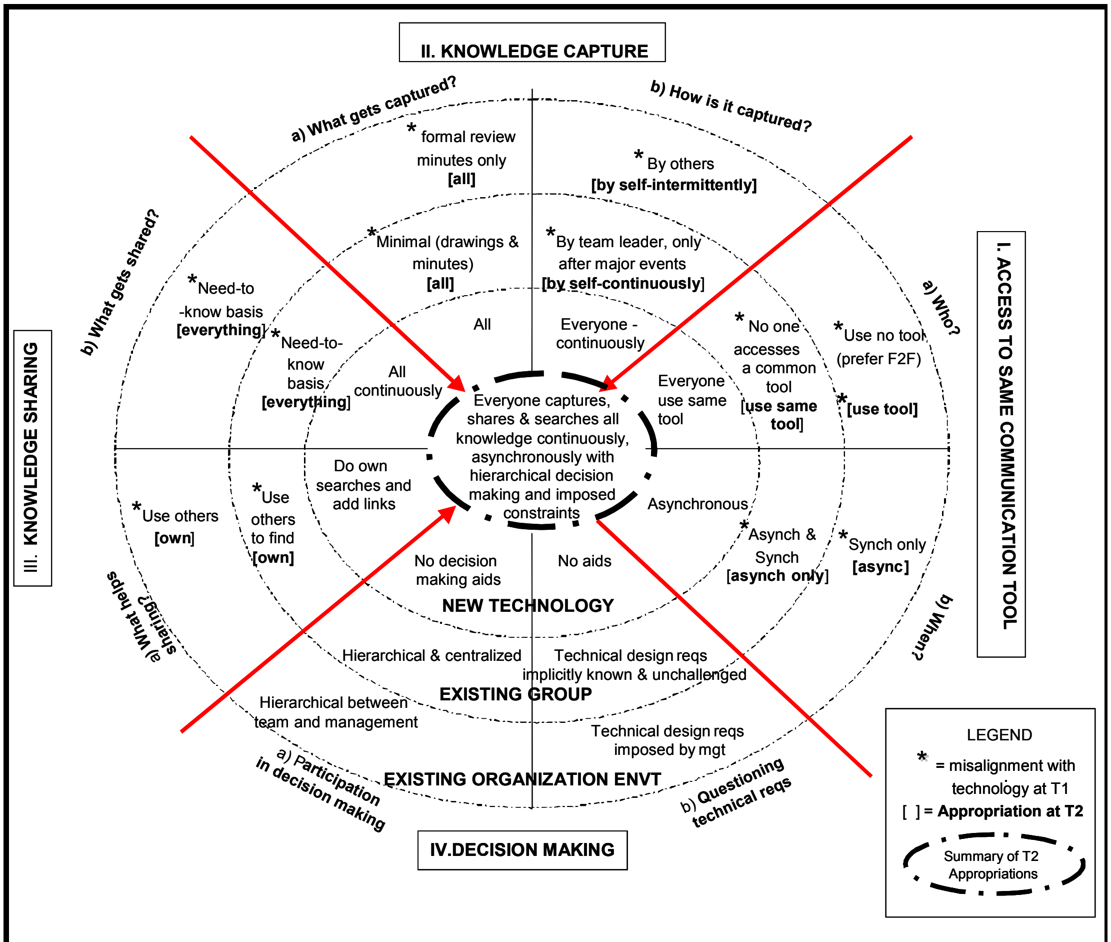

Figure 3. Misalignment of Existing Structures With New Technology at T1 and Appropriations at T2

tation that was misaligned to *how* they typically communicated with others (using face-to-face encounters not mediated by a tool), *who* they typically communicated with (the team leader, not all team members), *when* they communicated with the team (only in synchronous meetings, not asynchronously), *what* they communicated (formal minutes only, not informal comments), and their *reliance on others* to obtain needed information. Executive managers realized the extensiveness of these misalignments but agreed that a continuous review process might make it possible for managers to identify problems in a team's technical solution set early enough to help the team avoid wasting precious time and analysis resources. As a result, the seven executive managers who were responsible for the technical quality of the team's work agreed to have the tool installed on their desktops and to log-in regularly to review and comment on the team's progress. However, the management decided not to completely forego formal reviews; instead they decided to institute a formal review of preliminary concepts (i.e., sketches) halfway through the team's progress. Neither a continuous review nor a formal review of preliminary concepts had been used before at RocketCo.

To help managers with the continuous review, a keyword, "Management_Review" was created.

Team members were instructed to place in the CT under this keyword those entries that should receive management review, such as those of a more generally "formal" or polished nature compared to working entries. Managers were free to roam the Notebook, nevertheless. In addition, managers were provided individual hands-on training on the tool and then encouraged to log-in at will.

Appropriated Group Structure at T2

The spirit of the Internet technology created several misalignments in the way the team would have normally performed its task. The notion of ubiquitous computing was misaligned with *how* the group typically shared knowledge (no one used a common tool from which to share knowledge), *who* shared the knowledge (this was the lead engineer's responsibility), *what* knowledge was shared (just drawings and minutes), *who received* knowledge (only if needed), *who found* the knowledge (others), and *when* knowledge was shared (synchronously). Despite these misalignments, team members individually initially agreed to adapt their work processes. Interviews indicated that team members recognized at the outset the degree of change that using the Internet Notebook would pose but indicated they joined the team explicitly to do something different.

At the kickoff meeting, group members discussed the misalignments and generated a protocol for how they would like to behave, i.e., their norms of use. The protocol essentially accepted the spirit of the technology (ubiquitous computing), in large part because it painted a picture that was seen as enormously beneficial to the team members: it would save them from meetings, it would allow them the flexibility of working on the project when they had the time, it would ensure that they did not misplace valuable data, and it would help them understand what everyone else was doing on the team as they floated back and forth between their many projects. They agreed to use the Internet Notebook for *all* their communications, including putting an end to all face-to-face conversations. This only presented a potential problem for two of the members, who tended to see each other in the lunch room, but the other team members felt so strongly that they needed to be involved in all conversations that they persuaded the two members to agree to holding only public discussions, made accessible via the Notebook. The team members also agreed to try and document everything, from conversations to drawings, from using external application viewers to link to private analytic applications (where they could continue to use their own analytic models), to using a shared project management schedule to publicly track everyone's progress. The team members received training on the navigation tools and agreed to create three keywords for every entry that they put into the repository to facilitate later retrieval. Finally, they agreed that all members would have access to all information, agreeing not to create notebooks only privately accessible.

Summary of Appropriations at T2

The inner circle of Figure 3 summarizes the appropriations made at T2, i.e., within the first few weeks of the project. In addition, the data from which these descriptions of the appropriations are drawn are presented in Table 3, column 1.

Apparent from this description of the appropriated structures at T2 is that the team found it necessary to make numerous changes to the existing structures to resolve the misalignments. Of the three structures, group structures and organizational environment were changed. The team chose to leave the initiating technology spirit intact, despite having the possibility of working closely with the tool developer to make changes. That is, they accommodated to the technology spirit, rather than worked to adapt the technology spirit to accommodate their practices. Finally, the team did not make changes in the way decisions were made, since there were no obvious misalignments among the existing structures for decision making.

Result 3: What Was the Nature of Appropriations at T3?

Figure 4 presents the appropriated structures at T3, i.e., at the completion of the project. The figure follows the conventions of Figure 3 except that Figure 4 depicts with symbols whether or not

<table>
<tr><th colspan="3">Table 3. Summary of Appropriations and Discrepant Events</th></tr>
<tr><th>Appropriated Structures at T2</th><th>Appropriated Structures at T3</th><th>Discrepant events</th></tr>
<tr><th colspan="3">Who Has Access to Same Communication Tool?</th></tr>
<tr><td colspan="2">Technology Structure</td><td rowspan="6">• Managers log on and interpret work-in-progress as end result that lacks quality
• Managers can't make sense of project alternatives matrix
• Application viewer takes too long to launch for each entry
• Team confronts problem of sharing analysis models across platforms</td></tr>
<tr><td>SPIRIT: Managers and team members use common tool
FEATURES:
• Web browser makes tool accessible to all
• Use external application viewers to share documents— no need for common analysis models</td><td>SPIRIT: Restricted access to team only
FEATURES:
• Access limited to team
• Screen capture feature added, eliminating need for application viewer</td></tr>
<tr><td colspan="2">Group Structure</td></tr>
<tr><td>• Team agrees to use tool as their sole communication medium
• Team will continue to use own analysis models to analyze designs</td><td>• Team uses tool as one of many communication media
• Team uses tool for both communication and as a common analysis model</td></tr>
<tr><td colspan="2">Organizational Environment</td></tr>
<tr><td>• Managers agree to use tool to review team's progress</td><td>• Managers agree to NOT use tool</td></tr>
<tr><th colspan="3">When Do They Access Same Communication Tool?</th></tr>
<tr><td colspan="2">Technology Structure</td><td rowspan="6">• Team members too busy to logon once a day or to enter materials ahead of time; only logon in meeting
• Need synchronous interaction to make sense of entries
• Unplanned face-to-face encounters occur</td></tr>
<tr><td>SPIRIT: Leverage for asynchronous use
FEATURES:
• Server available 24 x 7</td><td>SPIRIT: Leverage for synchronous use as much as possible
FEATURES
• Couple the tool with audio teleconferences</td></tr>
<tr><td colspan="2">Group Structure</td></tr>
<tr><td>• Team agrees to logon once a day and do work asynchronously
• Team agrees to avoid face-to-face conversations</td><td>• All work that requires team decision making is done synchronously
• Face-to-face is OK if results documented in notebook later on</td></tr>
<tr><td colspan="2">Organizational Environment</td></tr>
<tr><td>• Managers agree to logon asynchro-nously and give comments when asked</td><td>• Managers agree to NOT use tool</td></tr>
</table>

Table 3. Continued

Appropriated Structures at T2	Appropriated Structures at T3	Discrepant events
	What Knowledge is Captured?	
Technology Structure		• Team member points out to team that information in public notebook could be subpoenaed • Team member voices unhappiness when a conversation he had is entered in Notebook • Transience and speed of knowledge generation makes capture of most knowledge futile
SPIRIT: Capture all knowledge FEATURES • Use templates to capture decision rationale and conversations	SPIRIT: Capture some knowledge FEATURES: • Text boxes for commenting rarely used • Templates for other than meeting minutes not used • Repository only includes drawings, analyses and minutes	
Group Structure		
• All knowledge gets captured	• Post decision rationale and conversations only when explicitly requested • Post analysis results and drawings at beginning of meeting but without annotations • Maintain private notebook	
Organizational Environment		
• Managers agree to use and post feedback	• Only formal reviews captured • Managers don't post feedback	
	How is Knowledge Captured?	
Technology Structure		• Pace of idea generation was faster than ability to sketch new ideas—brain-storming session stopped • Complex task requiring interactive idea generation and evaluation—asynch-ronous brainstorming unproductive • Managers aren't sufficiently know-ledgeable about tool to post comments • Team members too busy to logon every time they think of a project idea
SPIRIT: Continuously by everyone FEATURES: • Only one author can edit entry at a time, encouraging asynchronous use • Create sketches via drawing palette	SPIRIT: Capture only when designated FEATURES: • Put lock on entry creation to avoid overwriting during synchronous brainstorming • Scan in drawings before teleconferences • Use drawing palette to highlight, not sketch	
Group Structure		
• Members agree to try brainstorming asynchronously • Members agree to capture knowledge continuously as they think of ideas and comments	• Synchronous brainstorming done virtually aided by common-language metaphors • No unplanned knowledge capture, i.e., one member agrees to capture minutes, another agrees to scan in drawings	
Organizational Environment		
• Managers agree to use tool to review team's progress	• Manages agree to NOT use tool	

Table 3. Continued

Appropriated Structures at T2	Appropriated Structures at T3	Discrepant events
What Knowledge is Shared?		
Technology Structure		• Too many notifications during brainstorming • Knowledge too context-specific to be understood without verbal discussions • Most entries given keyword “design,” negating value of keywords • Entries too transient to create motivation to use keywords and reference links
SPIRIT: All knowledge shared asynchronously FEATURES: • History of entries specified through “precedent” reference-linking • Three keywords (maximum)/entry allowed • Automatic e-mail notification • Private-access Notebooks can be created	SPIRIT: All knowledge in Notebook shared, primarily during synchronous teleconferences FEATURES: • Reference-linking not used • Keywords minimally used • E-mail notification turned off • Private-access Notebooks not created	
Group Structure		
• All knowledge will be shared with everyone	• Maintain private notebook offline • Everything in Internet Notebook is information team agrees to share • Share only what is essential for others to see: drawings, analysis, and minutes	
Organizational Environment		
• Managers agree to have their knowledge shared	• Managers not using tool so revert to need-to-know	
What Helps Knowledge Sharing?		
Technology Structure		• Keywords and links of little value in finding entries • Group memory allows for quick recall without Boolean searches • Reference links to past entries not understood by others
SPIRIT: Do own searches and make links between entries explicit to help sharing FEATURES: • Entries easily navigated by date, keywords, or reference links • Use powerful search tools (e.g., reference link network, Boolean searches of multiple keywords) • No print feature	SPIRIT: Do own simple searches of individual entries but don’t make links explicit FEATURES: • Only simplistic navigation tools used (date and author) • Powerful search tools not used • Print feature added	
Group Structure		
• Do own searches and make own explicit links between entries • Search based on keywords or links	• I can’t find entry, ask someone in meetings • Search based on entry number, author, or date	
Organizational Environment		
• Use keyword “Mgmt_Review” to label management-oriented entries • Managers agree to search for entries with “Mgmt_Review” keyword	• Since tool not used, managers revert back to using others to find and share knowledge	

Table 3. Continued

Appropriated Structures at T2	Appropriated Structures at T3	Discrepant events
Who Participates in Decision Making?		
Technology Structure		• Posting all design ideas and analyses results in Notebook forced lead engineer to discuss each design idea and analysis result with team • Negative management review forced team to reconsider how they were interacting with management
SPIRIT: Adopt hierarchical structure FEATURES: • No decision-making aids	SPIRIT: Facilitate participation FEATURES: • Common repository to see what all team members do	
Group Structure		
• Hierarchical with lead engineer making all design decisions	• Participative discussions about each other's disciplines • Joint decision making on design	
Organizational Environment		
• Hierarchical with team leader responsible for all communication to managers	• Managers interface not with team lead but specialists	
Questioning Technical Requirements for Decision Making		
Technology Structure		• The Project Alternatives Matrix entry exposes interdependencies among disciplines • Specialists indicate an interest in understanding fundamentals of other disciplines • Negative management review makes explicit the paradox of justifying a non-traditional design based on traditional analysis methods
SPIRIT: Adopt existing practice FEATURES: • No aids to challenge technical requirements • Use external application viewers to share documents so don't need common analysis models	SPIRIT: Make assumptions explicit FEATURES: • Common repository available to all makes others' assumptions and the implication of management's technical requirements	
Group Structure		
• Specialists implicitly know own technical requirements • Technical requirements unchallenged	• Assumptions underlying entries questioned during teleconferences • Questioning causes technical requirements to be challenged	
Organizational Environment		
• Technical requirements imposed by management unchallenged by team	• Managers reconsider technical requirements	

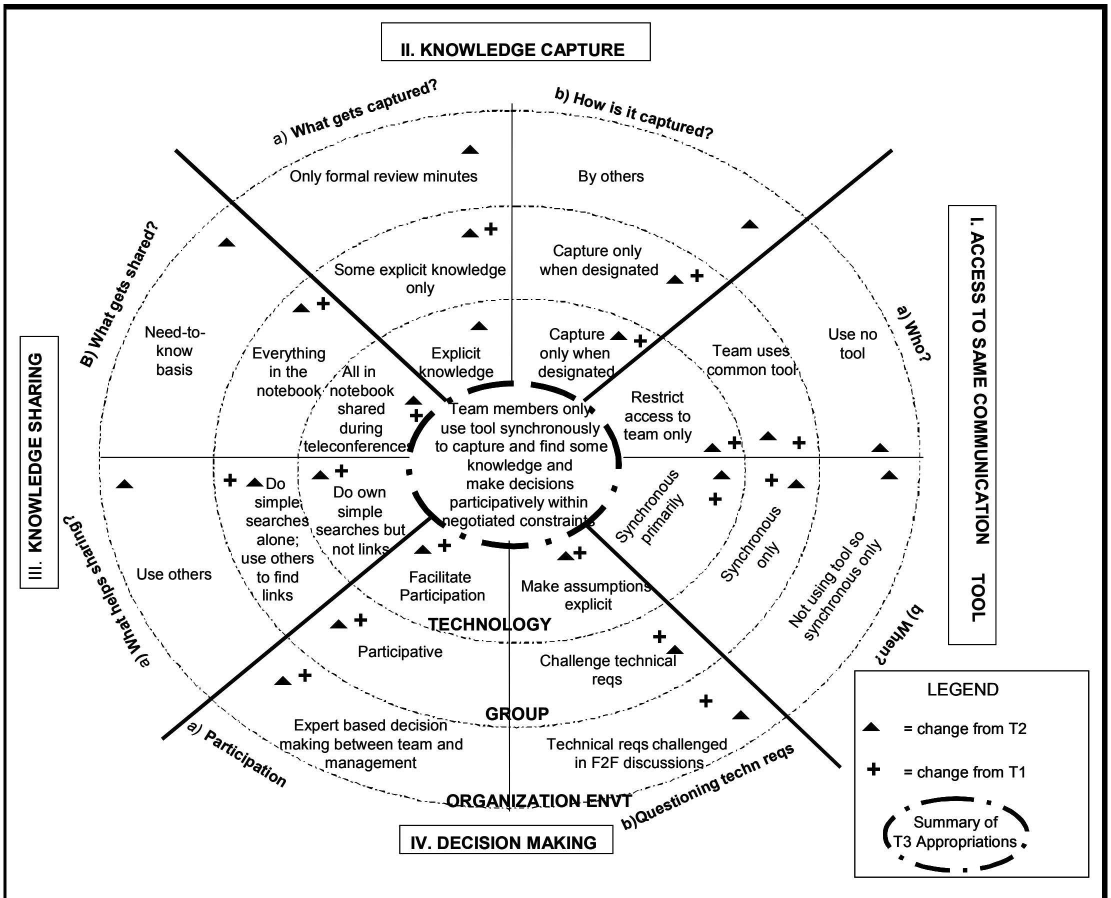

Figure 4. Appropriated Structures at T3

each structure at T3 represents no change (no symbol), a change from the structure at T2 (a black triangle), or a change from the pre-existing structure at T1 ("+"). In the text below, each of the T3 structures and the appropriations required to achieve them are described. In addition, the second column of Table 3 presents the data on which the interpretations about appropriations were made.

Appropriated Technology at T3

During the course of the project, the CT was itself modified in significant ways. Some of this modification was in the addition of new features, some in the decision to not use certain features, and some in the intent to which the features were used, i.e., the spirit or norms of use. As summarized using triangles in the technology circle in Figure 4, changes were observed in all appropriation topics.

With regard to access to the tool, access privileges were initially set to allow both management and team members access to the tool and members were expected to use external application viewers (called "Hot Links") to share their documents. Team members instead eventually limited access to only team members, deciding to exclude management. In addition, team members pushed the developer to create a screen capture feature, which eliminated the need for external application viewers. Team members also requested, and received, a feature that locked entry creation so that their entries would not be overwritten during synchronous brainstorming. Finally, the single most significant change was to couple virtually all use of the tool with a synchronous "meet-me" telephone conference. By the end of the 40 weeks of the project, 89 such audio/electronic virtual meetings had been held.

The technology was appropriated to facilitate knowledge capture as well. Although there were templates to capture decision rationale and text boxes for commenting on drawings, the decision rationale and comments were rarely captured, leaving these features mostly unused. In the end, the over 1,000 entries contained only explicit knowledge (such as formal drawings, analyses, and minutes), rather than tacit knowledge (such as conversations, assumptions, or interpretations). This knowledge was also not captured in the way expected: the audio portion of the virtual meetings became essential to interpreting entries, and knowledge was not captured continuously as it happened (such as by using the drawing palette to create sketches), but rather input as entries right before meetings (such as when drawings were scanned in) and then the drawing palette was used to highlight points being discussed during the meeting.

The appropriations for knowledge sharing also changed. For example, entries were generally not created with the use of keywords, despite the initial protocol that entries would be coupled with at least three keywords. Reference links to similar previous entries were sparse. "Private" entries for privately accessible notebooks, using personalized keywords, were not created. Because keywords and reference links were not generally used, only the simplest navigation and search tools (such as sort by latest date or author) were used. Finally, the team requested and received a print feature so they could examine and share drawings off-line.

Even the final appropriation topic of decision making experienced changes in technology. Although the spirit of the technology was to adopt the existing hierarchical structure, the most central feature of the technology—a common repository of all critical knowledge available to all on the team—resulted in everyone on the team asking many more questions about each others' ideas, drawings, and analysis results than in previous development efforts. This resulted, as will be explained in the section below, in a technology spirit that fostered more participation in the design process than the traditional hierarchical structure allowed.

In sum, as indicated by the triangle symbols in Figure 4, the final technology structure that the team adhered to required that the team change appropriations that had been agreed to at the outset of the project for *all* eight appropriation topics.

Appropriated Group Structure at T3

Initially, the Internet Notebook was intended to serve as a knowledge repository only, with team members continuing to use their own geometric models for the specialized analyses each performed. Over time, however, members decided to use the repository to house a single analytic geometric model from which the specialists could perform their analysis. This was unprecedented, because it meant that assumptions about parameters needed to be adopted across disciplines.

The availability of a common tool and common analysis model to share knowledge meant that, in principle, the lead engineer's role as information gatekeeper could be bypassed. This was, in fact, what happened; in addition, the lead engineer's role expanded and became more ambiguous. From being the hub in a communication wheel, he now had to get everybody to explain their inputs to others and at the same time negotiate with everyone publicly on which solution to adopt. Initially, the lead engineer found this role change very discomforting, complaining on more than one occasion about how "I've never seen a rocket designed by committee before." Over time, however, as it became increasingly clear that the lead engineer was unable to formulate a solution that would meet management requirements, the increased participation allowed the generation of more innovative solutions and an increased understanding of the solution by all team members. While the lead engineer reported in the final interview that he missed being in control (and several others commented that greater leader control might have been beneficial), he also recognized that his multiple time commitments would not have allowed him to simultaneously stay in control and generate the needed solution.

With this shift from a hierarchical to a participative decision making structure, the role of each team member shifted. While each specialist continued making their independent technical analyses, each member also began to engage in the design process more proactively. For example, when an entry of an analysis result was posted, specialists in other areas would not only query the specialist to understand what the results meant, but might even suggest alternative analytic interpretations of the results or question underlying assumptions of the analysis method. This led to questioning what had initially been accepted as management-imposed technical requirements for the design, a process that, in the end, led to a breakthrough solution.

While the tool housed more knowledge about the team's progress than had ever been captured before (with over 1,000 entries), the group learned during the project that they could not capture all the knowledge. Three weeks into the project, for example, a comment by the lead engineer indicated that he had had a "private" conversation with a team member. After much discussion about this conversation (e.g., what should be made public about it, how it violated the protocol for no face-to-face meetings, etc.), the team finally decided to sanction face-to-face meetings as long as the results of the meeting were documented later on. The team also found it increasingly burdensome to try and document everything publicly. So, instead of voluntarily documenting conversations and informal and tacit knowledge, team members began to only document this implicit knowledge when explicitly asked to do so, such as by other members during a virtual meeting. This often meant that virtual meetings were spent describing this tacit knowledge by explaining assumptions and context for each entry. Moreover, the team members began to accept designations or assignments as to what they were responsible for documenting (one member documented minutes, another scanned in drawings, etc.). In this way, it was no longer the case that everyone was responsible for documenting everything and that everything was being documented. The team members came to view the Internet Notebook, then, no longer as a repository of all knowledge, but a repository of the knowledge that the team had decided to enter. They still adhered to sharing all knowledge *that was in the Notebook* with all members of the team; just not sharing *all* knowledge.

A final significant appropriation had to do with brainstorming. At the outset of the project, team members were only familiar with the type of intensive, collocated brainstorming that formed the essence of their creative work, in which members confront, "read their eyeballs," gesture on boards, grab the marker, interrupt, and generally create new ideas through collective physical as well as intellectual actions. While the members had agreed to try brainstorming asynchronously (e.g., by members creating entries and others commenting on them), over time, it became apparent that members were able to brainstorm virtually, but not asynchronously.

Appropriated Organizational Environment at T3

For the executive management at RocketCo, the agreements they made for how they would interact with the virtual technology-enabled team to meet the needs of the team were changed in *all* eight appropriation topics. Comparing Figures 3 and 4 for Organizational Environment indicates that, for six out of the eight appropriation topics, they reverted back to their pre-existing environment. The managers didn't access the tool, they didn't share their knowledge by commenting on entries, they did not use the Notebook to search for relevant team knowledge, they did not publicly share informal knowledge, they did not work asynchronously with the team by typing in entries, and they did not personally engage in capturing their own knowledge—all practices they had promised to change from the way they normally worked.

In two areas, there were changes that reflected not a reversion, but a new structure. First, as team members began to use the entries and teleconferences to elicit and question technical assumptions underlying the proposed designs, the team developed a consensus about the impossibility of certain technical requirements that had been initially imposed by management. This consensus gave individual team members enough confidence to challenge management. Eventually, these challenges led several managers to reconsider technical requirements previously "written in stone" for all projects. Second, the participative nature of the team called the traditional hierarchical relationship with management into question. Since the most appropriate people to renegotiate technical requirements with management were disciplinary experts, limiting interactions between the team and management to the project leader alone no longer made sense. In fact, one of the team's virtual meetings explicitly focused on this issue of who should be speaking with the various executive managers. The team decided to pair up disciplinary specialists and managers and have these pairs resolve disagreements about acceptable technical requirements and solutions for the team.

Result 4: What Were the Reasons for Appropriations?

To find the reasons for each of the appropriated structure, we noted events that immediately preceded the change to the structure. For example, for the change in access to the Internet Notebook from everyone (including managers) to team members only (excluding managers), the immediately preceding event was that several managers had logged in and complained that the entries they reviewed lacked the quality of analysis they expected. In addition to noting preceding events, final interviews asked team members to describe their views as to why the changes occurred. The last column of Table 3 presents the list of reasons accompanying each change in each structure. Due to space constraints, we have focused our discussion below not on elaborating each reason but on describing the patterns across the complete set of reasons we identified.

Table 3 lists over two dozen reasons for changes in structures. These reasons for changes led us to recognize that these reasons were best characterized as "discrepant events," defined as an event that explicitly called into question an existing structure. A review of the events indicated that they could not be universally attributable to actions of management, limitations of technology, or inability of the group process. Nor is there one kind of event that occurred that had reverberating impacts on all other events and structures. Nor did they occur as part of a small set of discontinuities. Nor were the events seemingly rooted in the pre-existing structures; that is, an event didn't occur because it was somehow "destined" to occur, as when management pre-ordains that collocation is required to make decisions even though management may claim to try an alternative approach. Instead of finding a single way of characterizing the events, we instead found that the discrepant events seem to represent four recurring themes that the team struggled to resolve throughout the life of the project:

(1) how to overcome barriers to adding knowledge to a public repository (e.g., being too busy, knowledge transience, and an inability to clearly distinguish *a priori* between public versus private knowledge);

(2) what are the expectations for acting on shared information (as, for example, when management didn't like what they saw in the Notebook, they told the team, resulting in the team being demoralized and closing down access by the managers to the CT; when information about designs was openly shared, the lead engineer's job changed dramatically);

(3) how to overcome barriers to the use of search tools (e.g., lack of motivation to adhere to discipline for organizing knowledge; lack of proof that search tools are faster than people-connections); and

(4) how to share knowledge without the benefit of collocation cues (e.g., use of metaphors, screen capturing from past entries).

For example, there were many discrepant events that reminded the team throughout the project of the barriers to adding knowledge to a repository. These were only discrepant events because the team at T1 had optimistically envisioned a knowledge base containing all knowledge useful to everyone on the current as well as future design teams. Once the team scaled back from this vision and accepted a much more limited knowledge base, the discrepant events ceased.

Table 4. Project Outcomes by Team Members and Managers

Outcomes	Core Team	(N = 8)	Managers	(N = 7)
Meeting Design Target for	Mean	S.D.	Mean	S.D.
Manufacturing cost	6.3	0.4	5.3	1.5
Innovation in use of collaborative technologies	6.0	0.9	5.3	1.1
Innovation in injector design	6.0	1.0	5.3	1.1
Performance	5.3	1.2	4.7	1.4
Performance scalability	4.3	1.0	2.7	1.1
Manufacturing scalability	3.4	1.2	3.4	1.5

Note: "1" = Very ineffective to "7" = Very effective

These discrepant events, then, were not a function of pre-existing structures, but rather a function of ideals and expectations that the team had for itself. These expectations couldn't be fulfilled, not because any particular structure was a barrier, but because the existing state-of-the-art in the combination of technology, organizational environment, and group processes was insufficient. For example, while voice recognition systems could have captured all oral communication and videotaping could have captured the physical cues (actions actually tried by the team), the team members felt that it was often what was not said and the implicit conclusions drawn at the end of a particular design session that were more important to capture than each utterance. Yet, eliciting these inferences was difficult for the members because it might only be in later conversations that they realized they had made an inference. Thus, the discrepant events associated with the theme of capturing knowledge that the team encountered were created largely by inadequate technology-organization-group process solutions available to them for capturing the right knowledge at the right time in the right amount—and not simply because of recalcitrant or non-malleable structures thrust upon them.

Result 5: How Successful Was the Team?

By the end of the 10 month project, the team had generated over 20 different design concepts, with the final design concept passing the formal management review. The seven executives and eight design team members were surveyed at the end of the project and asked to rate the degree to which the team met its programmatic and technical objectives. As Table 4 indicates, all felt that the team had met design and innovation targets, except for scalability.

A final data point indicating that the project was a success was that 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. According to one executive manager,

> The team succeeded at designing 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. The team members achieved this success through collaboration.

The team received an award for outstanding achievement from RocketCo Senior Management.

Summary of Results

The findings can be summarized as follows:

(1) The team experienced significant misalignments among pre-existing structures at T1.

(2) At T2, to resolve the misalignments, the team modified the organizational environment and group structure, leaving technology structure intact.

(3) Discrepant events arose as the team tried to perform with the new structures.

(4) Discrepant events resulted in further changes to the structures at T3.

(5) The final structures at T3 represented significant changes to the T2 structures.

(6) The final organizational environment reverted back to its T1 state while the technology and group structures represented emergent structures different from both those at T1 and T2.

Answering Our Research Questions

What, then, are the answers to the four research questions asked at the outset?

(1) *Can the workgroup adapt any or all structures, or does it primarily try to adapt to the technology's initial spirit?* The workgroup initially changed the organizational environment and group structures but left the technology's spirit intact, as DeSanctis and Poole (1994) would predict. However, over time, as the team was confronted with discrepant events that indicated that they could not leave the technology's spirit intact if their performance goals were to be achieved, the team also changed the technology spirit. Thus, we found that, when a workgroup is allowed to modify its structures, it is possible that all structures may be changed.

(2) *Do pre-existing structures constrain the workgroup's adaptation process, even when these structures can be changed?* We found that the notion of pre-existing structures constraining the adaptation process was too simple, since the notion does not handle the complexity of what "constraint" means, as well as what "structures" mean. We found that, because the workgroup was allowed to change the structures, the structures were in fact changed; so, in this regard, they were not constraining. Moreover, we found that the pre-existing structures did not seem to predict the discrepant events; pre-existing structures were, therefore, also not constraining in this regard.

    However, we did find that organizational environment reverted back to its pre-existing structure, despite being modified at the outset by the team. Does this mean that the organizational environment is constraining? If constraining means that it constrained the other structures, the answer appears to be no, as the discrepant events that caused changes in technology and group structures were not necessarily due to organizational environment. If, however, constraining means that organizational environment was not malleable in the long run, that appears to be the case.

    Finally, we found that changes in structure were more attributable to discrepant events than to malleability of the structures themselves. For example, when the team stopped the first virtual brainstorming session, they did not blame the technology, organization, or group but instead realized that the problem was trying to capture everything they were doing during the brainstorming. As a result, the team continued electronic brainstorming but revised the protocol devised at T2. Thus, a change in technology structure came about because of the discrepant event of trying to capture too much information, not because of a structural constraint. Where do these discrepant events come from? We argue that they are derived from the lack of good solutions to difficult electronic collaboration problems, not (necessarily) from the unwillingness of recalcitrant structures to change. Deciding what to add to a public knowledge repository is a difficult question, even when structures are malleable.

Thus, to answer the second research question: some pre-existing structures may not be malleable in the long term (as was the case with organizational environment), but this lack of malleability may not affect how the rest of the structures are adapted. Instead, the adaptation process is more directly affected by discrepant events which may arise not because of structural constraints but because of the lack of available technology, organizational, and group solutions to solve a difficult coordination problem. Both malleability and discrepancy seem necessary, but not sufficient, except in their interaction.

(3) *After the initial adaptation to achieve alignment, does the workgroup experience the need for further adaptations?* We clearly found the need for further adaptation, but this need for adaptation did not arise because of an initial misalignment, as Leonard-Barton (1988) would have predicted, with misalignments recognized and gradually resolved. Instead, at the outset, the team had the opportunity to modify its structures so that they could achieve what they thought would be perfect alignment when they began their work, so further adaptation would not be necessary. In a sense, the team achieved within the first two weeks a set of aligned structures for their work process. As the work process unfolded, however, the team became confronted with discrepant events informing them that the "perfectly aligned" structures they had created were not working—not because they were necessarily misaligned, but because the emergent task demanded a different set of aligned structures. The team, over the course of the remaining 38 weeks, tried to find ways to create a new structure that would lead to successful performance. Thus, the process was not one of initial misalignment gradually reduced to alignment and successful performance, but of initial misalignment, immediately reduced to (presumed) alignment, followed by discrepant events creating modifications to structures that created new misalignments, followed by further changes to structures to reduce misalignments, etc. To answer this third research question, then: in the context of unpredictable work environments, having the opportunity to modify existing structures is not enough to eliminate the need for further adaptation. Indeed, we can imagine that some groups may *never* converge on a set of revised adaptations, spending most of their effort in adjusting, and finally achieving limbo, failure, or dissolution.

(4) *What is the nature of these adaptations: Are they discontinuous responding to windows of opportunity or are they continuous, gradually closing misalignments?* As indicated above, we found that the Leonard-Barton (1988) model of a gradual reduction of misalignment was too simple for the SLICE team. We also found, however, that the Tyre and Orlikowski (1994) model of discontinuous adaptations responding to windows of opportunities did not fit well. These discrepant events did not occur in batches; they occurred sporadically, individually, throughout the course of the project. Nor were the events perceived by the team members as opportunities; they were generally seen as problems that arose unforeseen and unwelcome. Finally, the events were not windows in the sense that there was not a short, fairly clearly bounded amount of time in which to resolve the discrepancy; for some of these events, it took the team many weeks to identify a new

structure that would resolve the discrepancy while, for other events, resolution came in minutes. The nature of the adaptation process as applied to SLICE, then, was one of adaptations yielding increased alignment, followed by an almost continuous array of discrepant events indicating that new structures were needed.

Why did Tyre and Orlikowski find discontinuous change characterized by relatively little change after the initial episodes, and we found sporadic and ongoing change? One possible explanation might be found in the nature of the cases. Tyre and Orlikowski argue that the costs to change were so high in their cases that, once the initial adaptation was accomplished, further adaptation was discouraged. For example, in one of their cases, the pressure for production was cited as the reason why there was little energy to solve new problems, thus discouraging additional adaptations. In the SLICE team case, however, the costs of *not* adapting were in fact much larger than the costs of adapting. We believe that the reason for this was that the technology was not simply a complement to the work of the team (e.g., work-arounds were not possible; Gasser 1986) and that impediments to the use of the technology were not merely annoyances. That is, unlike one of Tyre and Orlikowski's cases in which "changes could be done in their leisure time" (p. 106), the technology was critical to their work, with impediments having direct productivity implications. Thus, we believe that adaptations may become discontinuous when the costs to change are very high, and when the technology is large or complex; but when the costs to not adapt are higher, and when the technology is more malleable, the adaptations may become ongoing, if not continuous.

Discussion

Limitations

There are, of course, many methodological limitations of this study. As a small-sample single case study, generalizability cannot be assessed, except as the findings conform to findings already published in the literature or as the theoretical suggestions prove useful in later studies. The strength of the study, however, lies in the closeness and length of time in which we observed the team's behaviors. In addition, we have no reason to believe that the subjects were inherently different from other subjects we might encounter in virtual teams: they were all successful professionals in their own organizations who enjoy the challenges that virtual teaming brings. However, we do suspect that the task that the team performed—of inherently unpredictable work on a highly innovative design—is different from many previous studies of virtual teams. Therefore, more case studies are needed to test the generalizability of the team's behaviors to other cases of unpredictable and highly innovative work. In anticipation of that work, there is much we can learn today from the behaviors that the team adopted.

Theoretical Implications

Together, these findings suggest a revised or extended model of structural adaptation, one that integrates our findings with those of DeSanctis and Poole (1994), Leonard-Barton (1988), and Tyre and Orlikowski (1994). This model, presented in Figure 5, adopts the distinctions among structures suggested by DeSanctis and Poole as technology, group, and organizational environment. We also concur with them that appropriation moves lead to decision processes, which in turn lead to (ideally, but not always, positive) outcomes. In addition, however, we suggest that the effect of pre-existing structures on appropriation moves is not a direct one, as DeSanctis and Poole suggest, but is instead mediated by three factors: the degree of misalignment (from Leonard-Barton 1988), the malleability of the structures (Johnson and Rice 1987), and the occurrence of discrepant events (from Tyre and Orlikowski 1994). However, unlike the suggestion by Tyre and Orlikowski, these discrepant events are not necessarily discontinuous but rather occur potentially continuously over the life of an adaptation process (depending on the size, cost, and time frame). Moreover, the discrepant events do

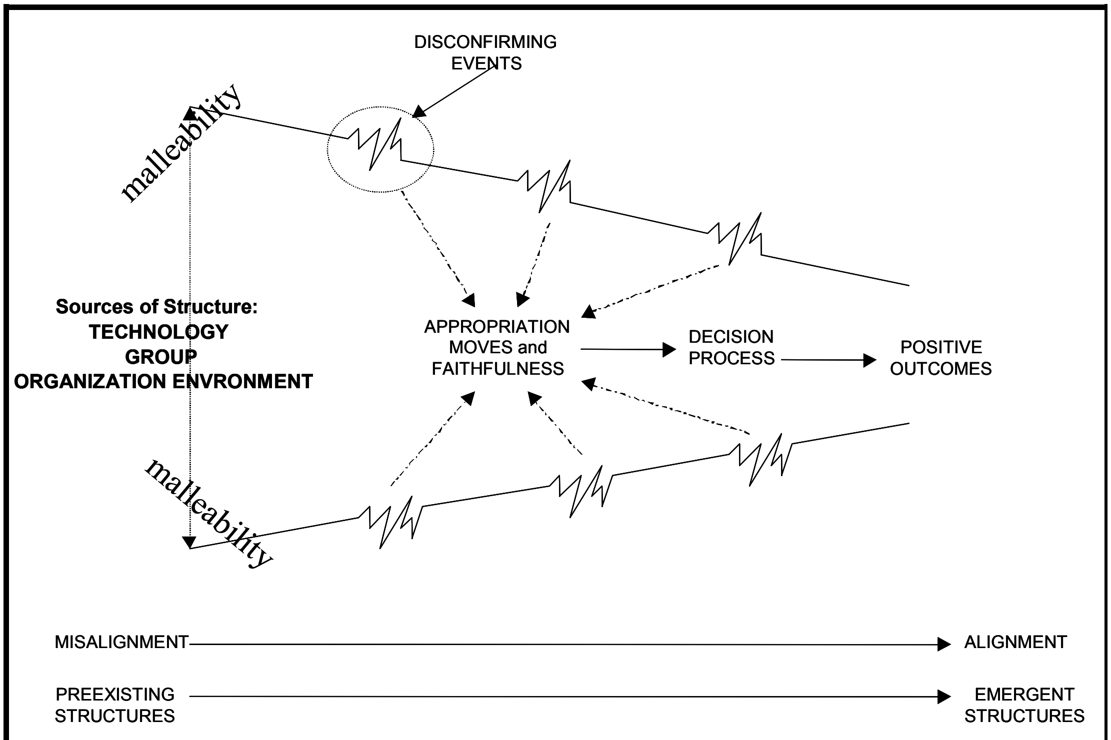

Figure 5. Model of Adaptation Process

not necessarily result from pre-existing structures as DeSanctis and Poole would suggest, but may instead arise from emerging events. The discrepant events can lead to increased misalignments (as suggested by Johnson and Rice), instead of the necessarily gradual reduction in misalignments that Leonard-Barton suggests. We concur with all the above models that emergent structures are likely to occur, but we suggest that these emergent structures may themselves create new discrepant events. We concur with the Tyre and Orlikowski and the Leonard-Barton models by suggesting that high-quality decision processes alone do not account for successful adaptation; alignment is required as well. Finally, we believe that any of these structures—technology, organizational environment, or group—are inherently able to change in this structuration process; one should not be seen as necessarily any more constraining than another, although in a particular context any particular structure's malleability may be restricted.

Thus, by examining a field setting in which malleability of all existing structures was heightened, we found that differences between the models could be resolved. The differences between Leonard-Barton and DeSanctis and Poole about whether certain structures are more malleable can be resolved with the conclusion that no structure is inherently more malleable than any other structure; the constraints typically attributable to non-malleable structures are more likely due to the field setting than inherent in the nature of the structure. The differences between DeSanctis and Poole and Tyre and Orlikowski about the size of adaptations can be resolved with the conclusion that the number or type of misalignments is less relevant to adaptation success than the resolution of discrepant events. Finally, the difference between Tyre and Orlikowski and Leonard-Barton about the continuity of adaptations can be resolved with our conclusion that adaptations are in response to the scale and frequency of discrepant events which will occur throughout a team's lifecycle.

The model we pose for resolving differences between previous models offers several suggestions for further research. First, the appearance of significantly greater constraints by technology spirit (or any other structure) in prior research may be an artifact of confounding malleability of structure with type of structure, time scope of the study, size and complexity of the technology, and costs and benefits of adaptation. Thus specific studies, as well as comparisons and reviews of structuration results, should consider the influence these factors may have in shaping the results.

Second, researchers should not assume that any particular pre-existing structure is necessarily fixed (though in practice certainly some of them *are* highly stable), as Griffith (1999) argues concerning technology features. Studies of adaptation processes should attempt to identify all salient misalignments and associated discrepant events and appropriations. *Thus, an "ideal" technology implementation should not be defined as one in which misalignments do not occur, because adaptations large and small will be needed, nor as one in which users faithfully hew to the technology's spirit; instead, an ideal technology implementation should be defined based on the ability of the team to resolve its own misalignments and the range of structures available to appropriate.*

Third, this study has provided some insights and a model that may help to incorporate research on virtual teams into the mainstream of information technology research by looking at virtual teams as a new organization with malleable structural conditions. Conversely, it also suggests that studies of collaborative technology must be well embedded within organizational and work group contexts.

Practical Implications

First, given the range and number of adaptations that occurred in the SLICE project, managers responsible for implementing new technology must allow adaptation in all three structures—technology, organizational environment, and work group structures—neither assuming that initial appropriations will be sufficient, nor that the need for adaptation can be avoided. This means that a key function of team leaders should be to make thoughtful choices about which structures should be malleable and which should be adapted, rather than to assume that adaptations are constrained by whichever structures appear to be most malleable. In addition, the critical role of discrepant events in reevaluating adaptation choices suggests that managers must create an environment in which discrepant events are openly discussed as a catalyst for recurring adaptations. Thus, managers may want to suggest adaptations not always because they are convinced *a priori* that the adaptations are correct, but because the adaptations may create discrepant events which, if openly discussed, provide insight for additional adaptations. The numerous adaptations suggest that designers of collaborative technologies (CTs) should not over-emphasize rigid technology features that cannot be adapted to changing needs of users. In accord with Griffith, we suggest that designers and implementers should better understand users' perceptions of features, rather than presume that their conception of the technology's spirit, and the associated features, are "fixed" structures. For example, CTs should be designed to allow changes in any initial coordination protocols as the team's relationships and understandings evolve. The CT should allow for just-in-time learning about the CT's features. Further, it is clear from the SLICE case that the team members gained a great deal from their teleconferences. This suggests that CTs should be designed with an expectation that they will be coupled with informal and oral forms of communication that are not necessarily face-to-face (Krauss and Fussell 1990; Kraut and Streeter 1995; Schrage 1990; Whittaker and O'Conaill 1997).

The SLICE case also identified four sources of discrepant events that virtual teams will encounter, including barriers to adding knowledge, clarifying expectations for acting on shared information, barriers to the use of search tools, and ways to share knowledge without the benefit of collocation cues. While we are not suggesting that virtual teams can resolve these issues at the outset, we are suggesting that CT developers and virtual team managers should attend to these issues in the preparation and support of the virtual team. Finally, our study suggests that virtual teams using new CTs need to allow themselves the flexibility to evolve their own knowledge-sharing norms over time. The team was provided sufficient autonomy to establish its own norms of interacting with a highly flexible technology, yet still changed those norms later on. This is perhaps not surprising. The workgroup literature (e.g., Gabarro 1990; Krauss and Fussell 1990) suggests that the process of developing "mutual expectations" is an iterative one since one's expectations are not clear until after some experience in working with others and on the tasks. Thus, frequent checkpoints, lessons learned sessions, and group reflections on the process should probably be the most stable norm of the team.

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