# Cutting into Collaboration: Understanding Coordination in Distributed and Interdisciplinary Medical Research

**Saeko Nomura[*1], Jeremy Birnholtz[*1,2], Oya Rieger[1], Gilly Leshed[2], Deborah Trumbull[3], Geri Gay[1,2]**

[1] Department of Communication [2] Information Science Program [3] Department of Education
Cornell University
301 College Ave., Ithaca, NY 14850, USA
{sn339, jpb277, oyr1, gl87, djt2, gkg1}@cornell.edu
[*]These authors contributed equally to this work.

**ABSTRACT**
Coordinating goals, schedules, and tasks among collaborators is difficult, and made even more so when there are disciplinary, geographic and institutional boundaries that must be spanned. Designing CSCW tools to support coordination in these settings, however, requires an improved understanding of the constraints and conflicts that impede effective collaboration. We present findings from a study of distributed collaborations between academic surgeons and biomedical engineering researchers. These two groups differ significantly in their work priorities and institutional contexts, but are nonetheless able to work together and coordinate effectively. They accomplish this via human mediation, frequent *ad hoc* communication, and optimizing the use of their limited face-to-face interaction opportunities.

**Author Keywords**
Distributed and interdisciplinary research teams, coordination issues, design implication, ethnography

**ACM Classification Keywords**

H.5.3 Group and organizational interfaces: *Computer-supported cooperative work.*

**INTRODUCTION**
Geographically distributed teams of individuals working together are an increasingly common facet of the modern workplace [7, 16, 18]. These teams are particularly important in science and engineering research, as the expertise and resources required to solve important problems are rarely located at a single institution [8]. The SARS crisis in 2003, for example, was rapidly addressed by an impromptu global collaboration [12]. Moreover, funding agencies in both Europe and the United States have invested significantly in "cyberinfrastructure" [2] and e-Science [27] to support large distributed collaborations.

Despite these growing investments and a widespread recognition of the importance of collaboration, however, effective distributed collaboration is often elusive. Recent studies have found, for example, that such projects are plagued by coordination problems [6], institutional constraints [4, 34], and difficulties in reconciling differences between disciplines [9].

While these studies identify some of the problems with distributed collaboration, they shed little light on how we might solve them. Thus, there have been several recent calls for a more detailed understanding of how distributed collaborations work on a day-to-day basis, particularly in environments where participants are in complex institutional contexts, and playing multiple roles that may have competing priorities [6, 26].

CSCW researchers have studied distributed collaboration for the past 20 years and have a great deal of knowledge and experience to contribute to this problem. At the same time, the development of collaboration tools in complex and nuanced research environments requires a detailed framework for understanding how research collaborations work and what they seek to accomplish [23].

In the paper that follows, we present preliminary results from an exploratory study that aims to contribute to the development of such a framework. We studied research collaborations between biomedical engineering (BME) researchers at a major research university and practicing surgeons at an academic hospital 240 miles away.

Despite both groups being academics, our participants represent two quite distinct populations. Surgeons, in addition to their academic research and teaching obligations, have clinical responsibilities that involve caring for patients who may arrive with or have life-threatening emergencies at any moment. To improve their capacity to provide care, their research interests tend to be clinical in nature and focus on the novel materials (*e.g.*, bioadhesives) and devices that their engineering colleagues can provide.


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BME researchers seek to create innovative solutions to important problems, so appreciate the surgery domain as an opportunity to have an impact and try out their ideas. Similar to the surgeons, the engineers are also strongly motivated by the more typical academic needs of publishing papers and securing extramural grant support.

We are interested in how these interdisciplinary and geographically distributed collaborators manage their joint work and coordinate their efforts, both successfully and unsuccessfully. Using data from detail-rich ethnographic methods, we describe the differences between the groups in addition to providing insights into how they manage coordination with theoretical and practical implications for the design of more effective CSCW tools.

## BACKGROUND

We focus here on characterizations of research work as it is carried out in different disciplines, and then more generally on problems of coordination in distributed work.

### Collaboration in Research

The subject of research collaboration has garnered substantial attention in recent years, as network-based communication and collaboration tools, referred to variously as collaboratories [8], cyberinfrastructure [2], e-Science [27] and cyberscience [27], have provided numerous and novel opportunities for researchers to bridge geographic and disciplinary divides [10].

Despite its increasing frequency [10], however, effective and efficient collaborative research can be difficult to achieve [6]. Nonetheless, effective distributed research collaborations are essential to the success of major scientific endeavors (*e.g.*, [9]). While there have been many studies of scientific work more generally (*e.g.*, [3]) and of collaboration in research (*e.g.*, [30, 34]), we lack a comprehensive framework for understanding the mechanics of these collaborations [5, 6, 26, 34].

As compared with other distributed collaborations, we argue that research collaborations are unique in three respects. First, they are typically voluntary – researchers engage in them only when it is perceived as expedient to do so, such as for leveraging the expertise of others, pooling resources, or gaining access to scarce research apparatus [13, 21]. Second, researchers typically enter collaborations as intellectual equals, rather than members of the hierarchies that may be more typical in business organizations. To be sure, research projects do have members with varying degrees of seniority and power (*e.g.*, PI status, tenure, etc.). The critical difference is that a prospective research collaborator cannot demand that a colleague work on a particular project in the way that a manager can in a business setting. Third, research work inherently involves a great deal of uncertainty about exactly what will happen [37], making it difficult to adhere to detailed project plans. These unique attributes require that special attention be paid to research collaborations. On the other hand, however, we will argue below that studying collaborations with these attributes also provide lessons that are more broadly applicable.

Moreover, interdisciplinary work presents an additional set of challenges. Clear differences have been observed between disciplines in terms of social and work practices [9, 15, 37,] and "epistemic cultures" [20] that could impact the ease of collaboration when these groups come together.

While there have been a large number of detailed ethnographic studies of scientific work practice (*e.g.,* [34]), only a few of these focus on the detailed coordination practices within collaborations. Fewer still are conducted with an eye toward the distillation of practical principles for CSCW applications.

Thus, our first goal in this exploratory study is to understand the work practices and coordination procedures in the research collaborations we studied, and move toward a theoretical framework for understanding distributed and interdisciplinary collaboration in ways that facilitate the development of CSCW tools.

### Coordination in Distributed Groups

The effective coordination of work in groups and organizations has long been an interest of researchers in organizational behavior [35, 36]. Coordination has been defined as the management of dependencies between activities [24]. It is the process that underlies effective group work in that it allows for mutual understanding and adaptation of work assignments and progress.

More recently, coordination and group structure have been of interest to the CSCW community in understanding both: 1) the conditions under which geographically distributed groups are most likely to succeed, and 2) how to provide groups with tools that enable them to coordinate effectively.

Olson and Olson [28] suggest that distributed work is most effective when "loosely coupled." By loosely coupled, they mean that the work can be relatively easily divided into "chunks" that can be assigned to individuals or collocated groups to complete independently. This is in contrast to more tightly coupled tasks that involve significant uncertainty about exactly what must be done, and therefore require more frequent interaction among participants [22]. Such interactions often occur opportunistically in collocated groups [29], but this may be difficult in distributed groups.

Hinds and McGrath [18] sought to move beyond the basic notion that loose coupling is more effective in distributed groups. They found that the ability to divide work up is helpful, but also that hierarchical structuring of work and communication may ease coordination.

All of this means that coordination in research collaborations may be particularly difficult. Research, as described above, has a high degree of uncertainty and can therefore be difficult to divide into clear chunks. In addition, research collaborations are rarely hierarchical, meaning that the communication and management structures discussed by

Hinds and McGrath [18] may be difficult to achieve. Moreover, in a study of research collaborations among multiple universities, Cummings and Kiesler [6] argue that collaborations with multiple partners tend to result in fewer coordination activities (*e.g.*, meetings, etc.) and fewer project outcomes.

Combined with what is known about informal interaction in distributed groups, we suggest that coordination in research collaborations may be particularly difficult because of the need for frequent interaction and troubleshooting. This need raises issues such as interpersonal awareness and informal interaction that have been important themes in the CSCW literature (*e.g.*, [33, 38]). We argue that a more complete understanding of research collaborations is required in order to bring this literature to bear on these settings.

Thus, our second goal is to tie the understanding of coordination that we develop to issues in CSCW, such as awareness and interaction, and to coordination in distributed groups beyond the context we study here.

## RESEARCH METHODS AND CONTEXT

Since November 2007, we have been conducting an ethnographic field study of collaborations between the Department of Surgery within the Medical College and the Biomedical Engineering (BME) Department in the College of Engineering of a large academic research university in North America. At this university, these departments are located on separate campuses, 240 miles apart.

### Initial Contact and Participant Recruitment

Since summer 2005, the Department of Surgery and the Biomedical Engineering Department have organized joint retreats twice a year at either campus. These events aim to promote collaborative research between the two departments. At retreats, surgeons and BME researchers give formal presentations on current research projects and surgical issues which they would like to study. Using these formal talks as a foundation, researchers who are interested in joint work toward a particular research goal or outcome discuss details of prospective projects informally during coffee breaks and receptions. For example, one surgeon introduced problems with currently available surgical materials and recruited research collaborators from the BME Department for a new material development.

We attended one of these joint retreats in February 2008, as well as the Department of Surgery retreat in November 2007, which a small number of BME researchers also attended. Our goals in attending these retreats were to get an overall sense of the research domain, and to recruit participants for detailed observations and interviews. During the retreats, we attended the presentations of research projects and observed participants interacting via formal presentations and informal discussions.

About 50 surgeons and BME researchers participated in the retreats we attended. Among them, four surgeons and six BME researchers agreed to participate in a longitudinal study of their research groups.

### Research Projects

In this paper, we focus on seven distributed and interdisciplinary projects which are conducted by above four surgeons and six biomedical engineers with their colleagues (See Table 1). The oldest project was launched in January 2006 and the most recent ones are still at the proposal stage.

Roles in the projects are typically separated between the two departments. The main role of the BME Department is to design and develop biomedical materials, mathematical models, and experimental or clinical devices. The role of the Department of Surgery is to clarify the requirements for the new materials and models to the BME Department, apply deliverables from the BME Department, share confidential patient data, and either conduct experiments (animal studies) or analyze the database of patients. During the development processes at the BME Department, tasks between two sites are typically not closely intertwined. They do, however, write the proposal, conduct experiments, analyze the database, and write research papers together.

### Ethnographic Observations and Interviews

We first visited the Department of Surgery in December 2007 to observe the four surgeons. We shadowed them for a week throughout their workdays to understand their daily

**Table 1: Research Projects between the Department of Surgery and the Biomedical Engineering (BME) Department.**

| | Project I | Project II | Project III | Project IV | Project V | Project VI | Project VII |
|---|---|---|---|---|---|---|---|
| **Dept. of Surgery Researchers** | Prof. A (PI) and Research Fellow B | Prof. C (PI), Assoc. Prof. D (PI), and Research Fellow E | Asst. Prof. F (PI) and Medical Student G | Asst. Prof. F (PI) | Prof. H (PI) and Research Associate I | Prof. J (PI) and Prof. K (PI) | Asst. Prof. L (PI) and Research Fellow M |
| **BME Dept. Researchers** | Prof. N (PI) and Graduate Student O | Prof. P (PI) and Graduate Student Q | Assoc. Prof. R (PI) and Graduate Student S | Prof. N (PI) | Asst. Prof. T (PI) and Graduate Student U | Prof. N (PI) and Asst. Prof. V (PI) | Prof. P (PI) and Prof. W (PI) |
| **Date Project Started** | January 2006 | July 2007 | October 2007 | January 2008 | January 2008 | Officially not started yet | Officially not started yet |
| **Status in April 2008** | The first paper primarily written by the Dept. of Surgery has been submitted. | Experiments are conducted by the Dept. of Surgery. | The first experiment was finished. The BME Dept. is writing the first paper. | Research grant has been funded. The BME Dept. will develop an experimental device shortly. | Research grant has been funded. Collaborative data analysis will start in summer 2008. | Research proposal writing is planned. | Research proposal writing is planned. |

routines at work and interactions with coworkers. We observed the surgeons at group research meetings, patients' wards, clinics, teaching sessions with medical students and residents, their offices, and the operating rooms. We also informally interviewed them while we walked together between rooms. Videotaping was not allowed, but we recorded interviews, took extensive written notes and, when possible, captured digital still images.

We returned to the Department of Surgery in February 2008 for a week of additional observations and interviews with three of the four surgeons, one senior administrator, two administrative assistants, two medical students, one resident, one research fellow, and one research associate who work with these three surgeons.

We also visited the BME Department in March 2008. Six faculty members, including two full professors, two associate professors, and two assistant professors, and five graduate students who work with these faculty members allowed us to conduct formal interviews.

In total, we had 23 participants from the two departments. Each interview session lasted 15 minutes to 2 hours depending upon the participants' availability. We adopted a contextually dependent interview structure, following up on issues we noticed during the observations. Each interview was video- or audio-recorded for later analysis.

### Data Analysis

At the field site, after every day of observations and interviews, all researchers met for a debriefing session, in which we summarized what we learned and wrote detailed field notes. Later, we also transcribed all interview and observation data on spreadsheets, and read and re-read them individually and with other researchers. We used all the materials to extract various themes which demonstrate overlapping phenomena and behaviors among the participants. We applied these themes as the framework for presenting our results.

## RESULTS

Given the above-mentioned difficulties inherent in distributed and interdisciplinary collaboration, we paid particular attention in our analyses to two themes: 1) problems in coordination experienced by our participants, and 2) the ways in which they overcame these difficulties. We use these two themes to present our results.

Although most of our participants felt their projects were successful and effective overall, we found evidence of periodic frustration with project coordination and communication. These difficulties stem from differences in work practice and priorities. There was evidence of clear strategies that helped participants confront and overcome these differences and difficulties.

### Factors Making Coordination Difficult

Difficulties in coordination for our participants stemmed from the different socio-cultural [19] environments in the two departments, particularly in terms of the different perceptions of hierarchy, roles played by participants, and scheduling priorities.

#### *Perceptions of Hierarchy*

While Hinds and McGrath [18] suggested that hierarchy in communication structure can ease coordination, we found that mutual respect for this structure was also a critical component of effective coordination. In other words, we observed cases where differing perceptions of group structure influenced participants' ability to communicate and coordinate.

These differences in perception stemmed from the distinct practices of the two departments, where the medical college was generally perceived as more hierarchical, both intellectually and behaviorally, than the BME department. Participants indicated, for example, that the chair of the surgery department had more influence over his colleagues by virtue of status than did the BME department chair.

We also observed directly that surgeons and professors were treated differently by junior individuals than were their BME faculty counterparts. For example, in the interviews, all medical students, research fellows, and administrative assistants referred to surgeons as "Dr. *last name*" and their co-principal investigators at the BME Department as "Professor *last name*", whereas graduate students at the BME Department referred to the faculty in both departments using their first names.

Although we did not observe evidence of a hierarchy between departments (*e.g.*, one field having higher status), there were differences in how hierarchies in each group were perceived by other project members. BME students, accustomed to being accorded respect by their advisors and local faculty colleagues, felt that they could contact surgeons directly, for example, when they had questions or conflicts. Surgeons, however, did not always perceive this to be appropriate or treat these emails as seriously as they did for emails from their faculty colleagues.

In one case, for example, a fourth-year PhD candidate, who has played a central role in the joint project, felt that the surgeon underestimated his abilities.

> "If I have a question to [first name of Assistant professor F at the Department of Surgery] and send an email to him and carbon copy to [first name of Associate professor R at the BME Department]. [Assistant professor F] replies only to my advisor, not to me. If I would not CC my advisor, my email could be ignored easily. This is recurrent things in the collaboration with medical school and it can be get used to it. […] So, when I want to talk with [Assistant professor F], I usually have to go through my advisor." (Graduate student S)

Although this surgeon emails this student directly when asking for data or questions about data interpretation, he has never replied directly to questions and requests from the student. Graduate students at the BME Department, therefore, need to ask their advisors to mediate their contacts with surgeons, which is a role they are unaccustomed to and

do not necessarily want to play. Thus, communication between these groups can be delayed and cause coordination difficulties.

Moreover, medical students and research fellows at the Department of Surgery said they have never emailed the BME professors directly. They do email BME graduate students because they are responsible for developing materials and devices, but think that higher-level coordination should be left to professors. In this way, we see that differences in perceptions of hierarchy can lead to misunderstandings and delays.

*Multiple Roles and Locations*

University faculty play multiple roles at work. They teach classes, conduct research, supervise students, serve on committees, write grants, and host research meetings, in addition to other tasks. Surgeons at academic hospitals have an additional important role: taking care of patients and conducting surgery. This is their primary role in addition to the other faculty responsibilities.

Because of these various roles, surgeons work at multiple locations and frequently move between sites. For example, most Tuesdays and Thursdays, Assistant professor L attends a surgical meeting from 6:30 to 7:30AM and supervises his residents and research fellows, goes to three different hospital wards to see more than seven patients by 8:30AM, moves to an examination room to conduct endoscopic inspections until 9:30AM, stops by his office briefly to do paperwork, and then goes to a clinic in a different building for outpatients from 10AM to evening. He is often invited to short meetings by his colleagues as he runs into them on his way to the next location. They rarely spend time at their office in the medical college.

Even for the research fellows and medical students who work with the surgeons in the same research group and know where they may work, it is often difficult to reach the surgeons because of the nature of patient-related work. For instance, Professor H has a special mailbox outside his office for exchanging papers with his students. According to his administrative assistant, often when his students stop by his office he is not in, so they will poke into the mailbox to see if he left them anything.

In the BME department, on the other hand, students said it is easy to get in touch with their advisors. Although BME faculty teach classes and attend research seminars a couple of times a week, they hold office hours for students in their group several times a week - such as Tuesday, Thursday, and Friday for the entire afternoon - when they are certain to be at their office. Even outside of office hours, students also said they can just drop by the advisor's office to have an informal conversation.

*Priorities and Scheduling*

Partly as a result of the surgeons' hectic schedules, one of the most serious challenges that BME researchers face in collaborating with surgeons is coordinating their schedules for carrying out the project, setting up meetings (both via technologies and face-to-face), and preparing for experiments at the medical college.

The academic surgeons reported that they find it difficult to secure time for research-related activities, because their top priority is patient care. Their schedules are set based on when they have to do surgery, attend to outpatients, and visit hospital wards. Often, research takes a backseat because of the essential nature of these services. The surgeons in our study often struggle to achieve all their goals both in the practice and research domains. For example, the basic weekly schedule of Assistant professor F, currently involved in three projects with the BME Department, includes operations, outpatients, seeing patients in the hospital wards, surgery and laboratory meetings, paperwork, and research, all scattered throughout the week. In addition, although he tries to secure time for research, it is often replaced by surgery, which cannot always be reliably planned for.

Consequently, surgeons often allocate time for research outside their official working hours. Furthermore, research time is sometimes fragmented, such as between operations and patients.

> "It also means that much of our work is done at night, and I'm in the hospital five or six nights a month, all night, and you might be able to get work done in an hour while you're waiting for an operating room." (Professor H)

Surgeons also have to contend with unanticipated interruptions. Although schedules are prepared in advance, they need to be ready for emergencies at any moment.

On the other hand, BME researchers have pretty consistent schedules with fewer urgent interruptions.

> "I build my schedule around things that are extremely concrete and written in stone. When I need to be in front of a class, I need to be in front of a class. And other things are kind of set in stone, like my weekly lab meetings, and faculty meetings. And then other things that are built around that." (Professor W)

BME researchers reported that they feel frustrated when they cannot get ahold of their surgery collaborators for more than a week or two. One BME researcher said that "the research schedule depends on surgeons' services, so it makes their experiments and research slow down. Working with clinicians is difficult. Once I went to the medical college to have a meeting with my collaborator. But I could not see him. He was called and gone for a day because there was a problem with his patient" (Professor N). Note that these two campuses are 240 miles away one another and it requires 10 hours of bus ride for a round trip. In addition of time, travel cost to the Department of Surgery contributes to BME researchers' frustration.

*Research Perspectives*

Surgeons are experts in human care and their main motivation in research is to contribute to medicine by improving the quality of patients' surgical care. If surgical products

work well for patients, they want to use them immediately. The BME researchers are, on the other hand, experts on materials and devices. As faculty at a university, their main research motivation is to publish research papers on their innovations. They value developing processes and prototypes, because these have to be verified scientifically.

The different motivations of surgeons and BME researchers lead to perspective gaps in understanding the nature and process of the proposed research. The notion of time scales, processes, and ultimate goals can often be quite different. Because surgeons usually desire a prompt result, BME researchers negotiate through a dialogue with them to reach an understanding that "science and engineering takes time to get results". (Assistant professor T)

> "Clinicians want to apply materials which our lab has already developed in different project to human-being right away. But actually, there is a long way to adjust the material to the specific clinical use, there is no shortcut, because our materials are general and there only be a potential to use in clinical cases. We need to do lots of trials. Clinicians don't understand that part." (Professor P)

BME researchers are also concerned that their work signify a contribution to engineering research and that they are not simply applying known techniques in service of the surgeons. This concern reflects the BME professional standards and requirements that academic faculty members must fulfill.

> "Well, so sometimes, building devices is OK to an extent, but we would also like to get involved in more of the science based projects." (Professor N)

### Strategies to Facilitate Coordination

As described above, there are several coordination challenges in the projects we observed. Nonetheless, participants felt their collaborations were successful on the whole. Here we describe the strategies our participants applied to cope with these challenges.

#### *Optimize Joint Retreats and One-day Trips*

To address the misalignments in research goals and perspectives, surgeons and BME researchers said that they try to take full advantage of the joint retreats, and one-day trips between two campuses (in Project VI) to talk over various aspects of their research in face-to-face.

Participants said that they try to attend retreats for the full day, so that they have opportunities to discuss their ideas with potential collaborators. One critical aspect of these discussions is aligning research goals and expected outcomes, and making initial plans for writing proposals for funding. As Professor N at the BME Department below mentions, these face-to-face interactions are useful in bridging the gaps in knowledge and research perspectives.

> "It's important because we're not trained in their area and they're not trained in our area. And we have lots of questions. And if you just rely on e-mail or papers, […] you get the information but you don't necessarily get the top priority, the key points, and you really have to go back and forth, face to face, to do that. So I think that at the initial points, these meetings back and forth have been very helpful. So when [Professor K at the Department of Surgery] took the day to come up here and meet with us all day long, that turned out to be very beneficial, 'cause we just learned a lot more, that we didn't know to ask the right questions. So after listening to him describe some of the things we didn't know anything about, then it became a lot clearer, certain aspects that we just didn't know. So that's sort of why I think the face-to-face meetings help." (Professor N)

In this way, the periodic retreats ensure that researchers from the two groups have opportunities to get together not only to exchange ideas and brainstorm about projects at the higher level, but also to develop a mutual understanding of each other's needs and goals that can be built on in the projects at a deeper level. This is significantly distinct from regularly scheduled face-to-face project meetings as has been described in other studies (*e.g.*, [6, 29]).

#### *Use of Human Mediators*

Surgeons and BME researchers both use human mediators to promote smooth coordination. Surgeons rely heavily on their administrative assistants in coordinating their hectic schedules, whereas BME researchers often rely on their graduate students for coordinating the actual work with their medical college colleagues during the experimental phase of the project.

Typically, everything related to a surgeon's schedule goes through the administrative assistant. They always know where the surgeon is and what he is doing there. This allows them to act as mediators between the surgeon and the many others – including patients, students and collaborators – who demand their attention and time. With this intimate knowledge of the surgeon's schedule, assistants can quickly make adjustments, and communicate these changes to those who are involved, and the surgeons make sure to keep their assistants updated with their ever-changing schedule:

> "We find new ways of contacting each other. He's usually good at telling me where he might go. I have his cell phone and sometimes we'll text just to get the message across, you know, like "I'm here and I'll be back." Usually we communicate throughout the day on email on the intercom and face-to-face, sometimes if he's going to a surgery and it's unexpected he might send me a text message." (Professor F's administrative assistant)

In the BME department, graduate students play an important mediating role, though it is different from the administrative assistants. For instance, BME graduate students and medical college researchers use email to schedule material development processes and experiments

Furthermore, being experts in the engineered materials used in the experiments, graduate students are often sent to the medical college after the material development phase of the project. They deliver the materials, explain the mechanisms of the materials and devices, help conduct animal experiments with medical students and research fellows, learn the experimental processes, troubleshoot when necessary, and report problems to their advisors.

> "I've discovered that it's useful for the student to be there when the experiment is actually done. To see what happens. Even if they couldn't do the surgery themselves, they will see firsthand,

> where the device fails–they always do the first time–how it failed, what was going on, because we can't rely upon the surgery people to describe it exactly. They will not necessarily tell us the most important thing that was happening that led to the device failure because they don't recognize it the same way we would. So it's really useful to have somebody there just watching what's going on and seeing what happens, and then talking to them at the time." (Professor N)

> "[Student S] went down there to show them how to manipulate the material. It's easier to go down and show them once versus sending out a whole boatload of material and having them play around with it and figure it out. And also I wanted to expose him to the animal work. […] So for an educational component, it's smart to send him down." (Associate professor R)

Despite our earlier observation that dissimilar perceptions of hierarchy sometimes lead to tensions in the communication between BME students and medical professors, the above two quotes by BME professors demonstrate that graduate students and medical students play an important role in mediating the actual work coordination between the co-principal investigators.

*Opportunistic Schedule Adjustment and Ad Hoc Meeting*

Because surgeons must change plans frequently because of last-minute urgent demands, they often ask their research collaborators to reschedule meetings and other events. Although BME researchers reported that they get frustrated if they cannot get ahold of surgeons, they said they are happy to reschedule as long as they are informed about the need to reschedule or the reasons behind surgeons' unavailability.

All of our participants said that they coordinate their schedules via email. When asked if they used shared online calendars, they said that using and updating such systems would make planning even more complicated, and would add an overhead to their already busy schedules.

When participants want to talk in real time with their remote collaborators, many said that they prefer videoconferencing to phone calls because they often need to draw images or show their products while discussing. Given the frequent schedule changes, however, pre-scheduled meetings can be problematic. Thus, *ad hoc* video-conferencing tools, such as desktop-based systems, are considered most useful because they can be integrated to their workflow.

## DISCUSSION

### Implications for Theory

From a theoretical standpoint, our bottom-up approach to this study has revealed many ideas that address issues raised in prior work on distributed collaboration.

*Extending Coordination*

First, we wish to urge those interested in coordination to consider the full context in which tasks and projects occur. While many studies of distributed groups focus on single tasks/projects, our results clearly show that people juggle many projects and play many roles (as has also been suggested in literature on, *e.g.*, self presentation [11] and organizational identity [31].)

Our results build on this notion by showing that these roles and responsibilities vary in priority and level of demand. Thus, even when people come into collaboration as equals playing the same role (in this case as academic researchers collaborating to solve a problem), differences in the other roles that they play (*e.g.*, clinical surgeon) can impact the effectiveness and ease of their coordination. Thus, we suggest that theories of coordination expand their focus to include differences in priority and other contextual factors that might impact the nature and ease of coordination.

In particular, such work could involve two issues. First is that people in different roles may view elements of coordination differently. Surgeons in our study, for example, clearly had a different view of scheduling than did the engineers. While the engineers could plan their schedules and projects well in advance, the surgeons had to constantly adjust their schedules.

This puts an interesting twist on the classic observation that scheduled work tends to drive out unscheduled work [25]. The observation suggests that organizations should schedule time for activities like research that might not be routine in nature, but could be eclipsed by scheduled and routine activities if the organization is not careful. While this observation largely holds true for the BME researchers we observed, the surgeons' unscheduled work (*i.e.*, surgery) was often top priority and forced rearrangement or postponement of the scheduled work, often to the dismay of their collaborators.

While coordination is fundamentally about the management of these dependencies [24], theories of coordination are often agnostic on issues of conflicting priorities and modes of managing these dependencies.

In the case of the collaborations studied, these differences in approach, combined with geographic distance which makes it harder to directly observe activity and to drop in on each other to talk informally about progress, sometimes led to minor conflicts and made communication critical.

We also point to the importance of human mediators in resolving these conflicts in coordination. In the case of surgeons, for example, their administrative assistants often played the important role of juggling elements of their schedule and interfacing with collaborators, students, etc. in order to bridge differences in coordination style between these different communities. Graduate students at the BME Department bridge knowledge gap with people in the Department of Surgery and facilitate collaboration.

Accounting for differences in roles, responsibilities and priorities in theories of collaboration could lead to better mutual awareness of what others are doing. This could be accomplished through the design ideas we outline below.

*Collaboration and Communication Structure*

The second implication of our work is a suggestion that the impact of collaboration and communication structure on

coordination may be subtler than suggested in prior work. While Hinds and McGrath [18] say that some informal hierarchy in the structure of group communication can ease coordination, our results suggest that, where communication structure reflects group hierarchy, there must also be mutual respect for that structure.

In other words, not all members of the collaborations we studied perceived the project hierarchies in the same way. It would seem on the surface that the collaborating groups appeared similar to each other. Groups in both the Surgery and BME Departments all consisted of faculty researchers who conceptualized and directed the projects and graduate students who did much of the "on the ground" research and analysis work. When we spoke to participants, however, their views of this hierarchy varied in important ways.

First, students in the BME Department often felt that they were not respected by the surgeons in that the surgeons often didn't reply to email or take them seriously. They frequently had to engage their advisors in the email conversation in order to get a response. And students in the surgery department tended not to talk directly to BME faculty – they usually communicated through the surgeon. These emails then often got forwarded by the BME faculty to their graduate students. Thus, communication structure was hierarchical – but did not result in more efficient communication or coordination. Rather, it frustrated some of the collaborators and seemed to slow things down.

The implication here is that when we take a more detailed look at coordination within specific collaborations, we see that it is not just the hierarchical structure that matters – there also needs to be mutual respect for and understanding of this hierarchy. Otherwise, coordination remains difficult.

Moreover, there were also differences within projects in how members of the collaborations perceived each other with regard to hierarchy and status. Some of the engineers felt that they were treated as developers by the surgeons, rather than co-equal collaborators in cutting edge materials research. Thus, even though collaborators came to the projects on theoretically equal terms, there were often conflicts in mutual perception. These were often resolved through face-to-face discussion at the retreats about everyone's research goals, but one can imagine how such perceptions could have impacted coordination had they persisted.

### Practical Implications

Our results point to several ideas that might be considered in the design of tools for coordination and communication in geographically distributed collaborations.

#### *Flexible and Dynamic Calendaring*

One clear finding from the data gathered in the medical school is that the hectic and dynamic nature of the surgeons' schedules constrained their opportunities for regular interaction with colleagues both at local and remote level. Administrative assistants update the surgeon's schedules on a regular basis, and they play a mediating role in helping others to understand what is going on in the schedule, and when might be a good time to talk to the surgeon.

These circumstances raise an important difference between existing shared calendar tools and the communication needs of our participants. Current shared calendars mimic paper calendars in that they support the explicit allocation of specific blocks of time to specific activities. This allows for people to schedule events like meetings, and also provides some awareness to others of what others are doing (as we discuss in more detail below).

Our participants, however, were often less interested in firmly scheduled meetings than in just getting the chance to talk to a very busy remote collaborator when that person has a minute. While local colleagues often have the chance to drop into someone's office or spontaneously encounter each other in the hallway, remote colleagues do not have these opportunities.

We therefore suggest that one way to enhance existing calendar tools would be to have a feature that allows users to, essentially, email each other's calendars with a request like "Call me when you have a minute. I'll be available at these times." Provided that both users use some sort of calendaring system that is updated as their schedule changes, the system would then provide a notification when the first overlap in available times arose.

Many of our participants reported sending emails like this, but that these emails were sometimes ignored. This is likely because emails can deal with a range of topics and be from a range of people. The dynamic calendaring system would be available only to a small number of trusted colleagues, who could be assigned priority order. These requests could also be finalized by an administrative assistant.

Another calendar feature that needs to be assessed is the meeting attributes such as importance (important to less important) or access (confidential to public) levels. The meeting attribute selections tend to represent regular office work characteristics and often do not accommodate features that may be required by those involved in distributed and complex collaborations.

#### *Improved Activity Awareness*

In the collaborations we studied, team members were frustrated when they did not hear back from their remote collaborators. Our results suggest that this frustration likely results, at least in part, from their being distant from each other and lacking awareness of what their collaborators are doing and where they are, and the many demands on their schedules and locations – that a patient needed immediate attention in the operating room, for example.

While developers of awareness systems and media spaces have addressed this to some extent in both desktop [14] and mobile [17] environments, the context we studied suggests novel ways of bridging these two types of awareness.

In particular, the surgeons work in a medical environment that is dynamic and involves frequent time-sensitive work that must take place in specific locations [32]. The engineers, on the other hand, do work that more often takes place in offices and is more regularly scheduled.

To bridge these work environments, we make the following recommendations:

First, awareness information need not concern only present activity. While awareness systems typically provide information about present activities for the purpose of indicating availability, our results suggest that information about past and recent activity may be useful as well. Knowing, for example, that a surgeon unexpectedly had to come into the operating room late last night could help explain why he or she missed an early meeting or did not respond to an email.

Second, location information should be merged with desktop awareness applications [17]. While exact and current location need not be shared if this is not desired, it is clear from our results that a surgeon's location may reflect a great deal of information about what he or she is doing, and that this information could be useful to collaborators. This information could be visualized in ways that do not compromise privacy, but do provide enough information such that tension between collaborators could be minimized.

At the same time, however, we must also bear in mind that such uses of technology invite user adaptations. Using location-sensitive mobile devices could, for example, result in surgeons placing the devices in the operating room when they wish to be perceived as too busy to reply, even though they are not actually in the operating room. As Aoki and Woodruff [1] point out, there may also be some utility in leaving room for ambiguity in the system. These are the subtleties that human assistants and mediators can effectively manage, but that systems do not handle as well. Exactly how to do this in the context we studied requires further research, but the importance of human mediators does suggest that designers should bear these factors in mind.

## CONCLUSION, LIMITATIONS, AND FUTURE WORK

This study illustrated the coordination challenges faced by researchers engaged in interdisciplinary and geographically distributed medical research projects, in addition to some strategies used for overcoming these difficulties. As preliminary results, we found that 1) different perception of hierarchy, 2) different practices in prioritizing and scheduling because of the multiple roles of academic surgeons as a practitioner and a researcher, and 3) different research perspectives between researchers at the BME Department and the Department of Surgery impacted the nature and ease of coordination. To address these coordination issues, they utilized human mediators, short-term but intensive face-to-face opportunities, opportunistic asynchronous schedule adjustment, and *ad hoc* synchronous computer-mediated communications. From these results, we provided insights for designing more effective CSCW tools among distributed and interdisciplinary collaboration; we suggested that the full context of the project, such as different roles, perspectives, perception of social relationships and collaboration structures among collaborators should be considered.

While our work provides some valuable lessons for understanding and supporting coordination in geographically distributed groups, the work has several limitations that suggest that our results should be interpreted with caution. It also provides several directions for future investigations.

We have studied a small number of projects within a specific institutional context. While these projects have many factors in common with research collaborations more generally, such as a high degree of uncertainty and the needs to publish papers and attract extramural funding, these results may not generalize to all settings. Our data do, however, provide rich detail on the projects we did study, and such limitations are common to all studies of this nature. In addition, the multidisciplinary *and* distributed nature of these projects make it difficult to isolate which of the observed difficulties can be attributed to geographic distribution, and which to multidisciplinarity. While our data lead us to believe that coordination would have been easier if the groups were on the same campus, we cannot say so conclusively.

In terms of future work, we first recommend longer-term, more coarse-grained studies of collaboration that allow us to better understand high-level coordination styles as they relate to various metrics of project success, such as meeting proposed timelines, publication/patent outputs, and novelty of the results. At the same time, we also recommend short-term studies of micro-level coordination on projects to better understand the mechanisms in play in such collaborative practices as writing proposals and doing data analysis in distributed groups.

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