Handbook of Research on Socio-Technical Design and Social Networking Systems

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Chapter XXXIX
Enabling Remote Participation in Research[1]

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ABSTRACT

This chapter uses the theoretical notion of common ground to explore remote participation in experimental research. On one hand, there is a desire to give remote participants the same views and capabilities that they would have as local participants. On the other, there are settings where experimental specimens and apparatus are large and difficult to effectively manipulate or view from a remote vantage point, and where multiple and diverse perspectives may be useful in decision making. In exploring these issues, the authors draw on two studies of researchers in the earthquake engineering community. The first, an interview study about attitudes toward teleparticipation, suggests that engineers are wary of remote participation because they fear the inability to adequately detect signs of potential failure. The second study, an observational study of researchers conducting an experiment in a centrifuge facility, illustrates that researchers adapt to the available information, and that diverse perspectives and information may be valuable in troubleshooting.

The way a team plays as a whole determines its success. You may have the greatest bunch of individual stars in the world, but if they don't play together, the club won't be worth a dime.

—Babe Ruth

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INTRODUCTION

Ubiquitous information and communication technologies are having transformative effects on the ways in which people socialize and work together. In particular, "virtual organizations"—aggregations of individuals, facilities and resources that span geographic and institutional boundaries—are an increasingly common work structure in a range of settings (DeSanctis and Monge, 1998). Virtual organizations enable interaction between individuals with diverse and varied perspectives who might not otherwise work together (Birnholtz and Horn, 2007), the sharing of expensive and scarce resources (Finholt, 2003, Kouzes and Wulf, 1996), and allow for novel ways of accomplishing tasks and solving problems (Atkins et al., 2003, Nentwich, 2003).

Among the many potential benefits of these technologies, the facilitation of increased access to scarce research apparatus and resources was among the first to be explored (NRC, 1993, Finholt, 2003). Consequently, a range of collaboratory projects have sought to increase access to and aggregate data from remote shared instruments (Olson et al., 1998), and to provide remote manipulation capabilities for laboratory apparatus, such as microscopes (Kouzes and Wulf, 1996). While these examples are specific to the research domain, the lessons learned can also be applied in areas such as telemedicine or remote consultation on repair of complex devices.

A key issue when providing access to remote instruments is providing all participants in the activity, both local and remote, with enough information to have an adequate shared understanding of what is taking place—that is, what Clark and Brennan (1991) refer to as *common ground*. As Birnholtz et al. (2005) point out, however, the amount of information and interaction needed to achieve common ground depends significantly on the *grounding constraints* (Clark and Brennan, 1991) present in the specific situation at hand. Some situations require more detailed discussion and may require more information, while others have simpler requirements. How to predict in advance the grounding needs for a particular situation, however, remains an open question.

This is a particularly important question for the realm of providing shared access to research apparatus and instruments. There are a number of modes of collaboration, ranging from traditionally structured projects involving a small number of investigators working closely together, all the way to distributed "mass collaborations" like NASA Clickworkers (Kanefsky et al., 2001) or the ESP game (von Ahn and Dabbish, 2004) where distributed collaborators contribute effort, but make no intellectual contribution to the project. There's also a vast space in between these two extremes; Wikipedia, for example, probably sits more toward the latter category, but it does allow for some more cerebral contributions. Given the various grounding needs and constraints due to the wide range of participatory modes for distributed collaborators, an important design question is therefore how we should think about providing information to remote participants.

In this chapter we report on our involvement in the development of the George E. Brown, Jr. Network for Earthquake Engineering and Simulation (NEES), a cyberinfrastructure project aiming to interconnect large-scale earthquake engineering (EE) laboratories. One goal of NEES was to enable remote participation in EE research. This research area and others like it present an interesting puzzle for e-science. On the one hand, the scarcity of laboratory facilities strongly suggests the value of using network technologies to increase access by scientists at "peripheral" universities to laboratories at a small number of "core" universities. On the other hand, though, the scale and potential danger in the research seem anecdotally to lead many researchers to reject outright the idea of serious scientists participating remotely in laboratory research.

BACKGROUND: PERSPECTIVES ON PARTICIPATION

One goal of e-science and cyberinfrastructure programs is to enable new forms of geographically distributed collaboration and participation in science (Nentwich, 2003, Atkins et al., 2003). Such distributed collaborations can take many forms, ranging from asynchronous collaboration via shared computational and database resources to synchronous remote participation. The degree of remote involvement can vary from passive observation to active manipulation (e.g., Kouzes, Myers and Wulf, 1996).

This wide range of participation modes has important implications for our understanding of communication in collaboration, and in particular for theories of common ground in conversation. On the one hand, some studies have shown that it can be more difficult for distributed groups to reach common ground—a state of shared understanding in conversation (Fussell et al., 2000, Clark and Brennan, 1991, Olson and Olson, 2001). This would suggest that more detailed information and a more realistic experience for remote participants will be useful in ensuring that common ground is reached as quickly as possible. At the same time, however, different modes of participation have different "grounding needs" (Birnholtz et al., 2005). In other words, there are cases where participants do not need a high degree of common ground to accomplish their task, in which case large amounts of shared visual information may not be beneficial, and may actually be harmful.

The first and most common design approach to remote participation seeks to approximate for remote participants the experience of actually "being there." In the simplest case, a single networked video camera can provide views to passive observers (Postek et al., 1999), and some basic camera manipulation can be provided.

Combining video or other data views with lightweight chat (Birnholtz et al., 2005, Olson et al., 1998) can allow remote participants to move beyond passive observation, and ask clarification questions or provide suggestions in a relatively unobtrusive way. Others have experimented with the provision of physical robotic avatars that can be controlled by a remote participant and include cameras and other communication functionality (Paulos and Canny, 1998, Jouppi, 2002).

One common trait shared by many of these systems is their focus on small objects that can be seen within a single screen, or specimens that are so small that they would need to be viewed on a screen even locally (like the nanoscale objects in the Nanomanipulator). When the research apparatus entails more than can be viewed on a single screen, enabling remote participation may be trickier (Ranjan, et al., 2006).

Adopting an alternative approach, Hollan and Stornetta (1992) argued that seeking to approximate "being there" is a potentially debilitating constraint on the design process for remote participation technologies. Even the best video and audio links offer constrained views and are limited to what can be effectively captured by cameras and microphones. Designers, in other words, need to think beyond replication, and toward innovations that exploit the unique attributes of the technologies being used.

There have been some examples of asynchronous remote participation attempting to bring the "beyond being there" approach to bear on technologies for e-science. NASA's ClickWorkers program, for example, made use of thousands of amateur space-enthusiast volunteers to effectively identify craters in a massive set of Mars photographs (Kanefsky et al., 2001). This example suggests that there is potential value in enabling novel forms of distributed participation in e-science, but leaves open our initial question of how to accomplish this for synchronous participants in large-scale laboratory experiments. There have been few examples of effective remote participation in such work.

"Beyond being there" approaches to remote participation are different from those that attempt to *approximate* "being there" in that they present different challenges when it comes to providing information for grounding. In the two studies we below, we present our findings with respect to the grounding needs and requirements, and discuss ways in which "beyond being there" approaches might be beneficial. We will show that:

1. Experimental earthquake engineering researchers were pessimistic about the potential

for remote participation, in part because they doubted that would be able to accomplish their goals for the research without being physically present

2. In one particular experiment we observed that had many characteristics of remote participation scenarios, the researchers were able to adapt and successfully complete the experiment because they were able to communicate effectively and bring diverse perspectives to the conversation.

RESEARCH CONTEXT AND METHODS

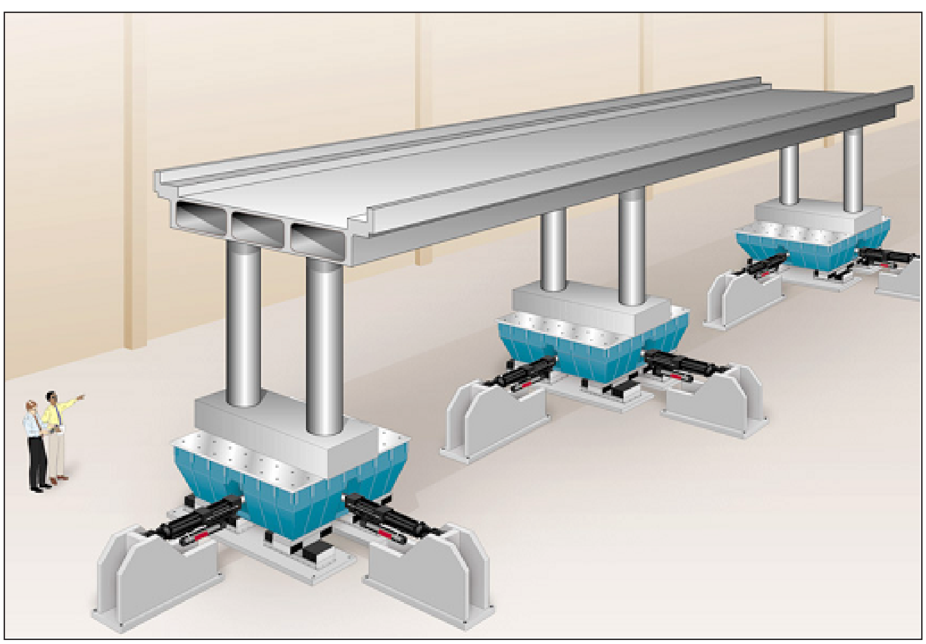
We present results from two studies in this chapter, both of which take place within the overarching context of the experimental earthquake engineering research community.

Experimental Earthquake Engineering

Earthquake engineering (EE) research is concerned with understanding the responses of materials, structures and soils to seismic forces. Work consists of field evaluation of structures, numerical simulation, and laboratory tests of physical models. Our work here is primarily concerned with the conduct of laboratory tests.

In a typical lab test, a full-size or scale model of a real-world structure is constructed, instrumented with sensors, and placed on a large testing apparatus such as a concrete *strong wall*, large shaking platform (Sims, 1999), or a centrifuge (Zimmie, 1995). Graduate students take several weeks or months to build the model, or *specimen*, under the supervision of faculty and technicians. The specimen is then subjected to a series of pre-orchestrated, increasing stresses, which reproduce ground motion from actual earthquakes at various scales, until the specimen experiences structural failure. Given the scale of these experiments and the use of materials like concrete and steel, unexpected failure of the testing equipment or the specimen itself can be dangerous or harmful, and waste large amounts of money and effort.

Figure 1. Artist's rendition of a full-size bridge deck that spans the three shaking tables in the structures lab at the University of Nevada, Reno



NEES: Cyberinfrastructure for Earthquake Engineering

We studied this community in part because our research team was involved in specifying the user requirements for The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) (NEES, 2006), a National Science Foundation project aimed at improving research, education, and practice in EE. The initial NEES project included funding for constructing or upgrading EE testing equipment at 15 universities across the United States as well as developing a computing infrastructure to enable collaboration among researchers, educators, and practitioners.

Methods

Between October 2000 and October 2003, members of our team visited fifteen universities that received NEES-funded equipment and one that did not. At these sites we conducted a combination of interviews and observations. We also were participant observers in the first trial experiment conducted with the NEES system.

Interview Study

We interviewed 94 participants at fourteen sites, including faculty, students and technicians. All interviews lasted 20-60 minutes, were semi-structured, tape-recorded and typically conducted by two of us: one person asked questions, while the other took notes. The note-taker typed full interview notes for each interview afterwards, consulting the audiotape when details were unclear. The same basic interview protocol was used for the interviews, but this was iteratively refined as the project progressed.

The protocol typically included 10-15 high-level questions, and probes were used to get more detail when necessary. Emphasis on specific issues was shifted based on the participants' experience and expertise, but questions generally focused on the process of conducting research investigations, from idea to published paper. As part of this, we asked participants if and how this might change if they had remote collaborators. We asked, for example, what their concerns might be, what they would want their collaborators to see during the investigation, and if they had ideas for involving remote collaborators in their work. In carrying out preliminary coding, we realized that our participants had significant concerns about remote participation in their research, and that these were largely centered around the issue of being able to detect and prevent catastrophic failures.

This overarching theme guided another examination of our data in which we extracted the categories used to present our data below: 1) the use of many sensory cues, 2) the variable likelihood of failure, and 3) the utility of integrating multiple viewpoints.

Centrifuge Lab Observation

In October, 2003, two members of our research team spent three days observing scientists conducting a geotechnical centrifuge experiment. The data we collected consisted of video recordings of the control room and the individuals conducting the experiment. We were easily able to fade into the crowd and observe unobtrusively, asking questions and taking notes during relatively quiet times.

The first day of the centrifuge experiment was spent finalizing the preparation of the soil box specimen. The box had been filled with a precise mix of soils and structures over the preceding two weeks. It had been transported via forklift from the specimen preparation building to the centrifuge rotunda the night before we arrived. After the specimen was placed on the centrifuge arm, the scientists plugged over 100 sensors into the data acquisition system and tested them. Additionally, video cameras were placed on the specimen in the proper locations, and various other parameters were checked in preparation for spinning. There was little activity in the control room on the first day, so we gathered no video data.

The second day was spent primarily in the control room, where we videotaped activity for five hours.

Activities on this day included testing instruments without spinning the centrifuge, and then spinning up slowly to gather baseline data.

The third day was also spent primarily in the control room, with the centrifuge spinning. Another five hours of video data were gathered during this activity. Activities on this day were largely similar to the previous day, except that baseline data were gathered at full speed and simulated earthquakes took place. At multiple points in time, it was difficult for the EE researchers to discern precisely what was taking place with the specimen, and much negotiation and discussion ensued.

Following the observations, videos were transcribed, along with a brief description of who was in the shot and what was taking place. These transcripts were used for the analyses described below.

To analyze the data, we used inductive qualitative techniques. First, we identified *uncertainty episodes* where a breakdown in the normal workflow occurred. The breakdowns took two forms: miscommunication or misunderstandings between researchers conducting the centrifuge experiment, and confusion about unexpected or anomalous instrument readings. We then examined each uncertainty episode for evidence of the cause of the breakdown, and how it was resolved so that work could be resumed.

STUDY 1: FAILURE PREDICTION DURING EXPERIMENTS

Specimen failure is most likely to occur very early or very late in the testing process. Interestingly, failures that occur early in the testing process are always undesirable, while only some failures late in the testing process are undesirable. This is because early failure is typically a sign of a flaw in the design or implementation of the specimen or testing apparatus, and occurs before the desired data have been collected. Late failures, on the other hand, occur after such data have been collected and the data collected during failure is often part of the planned testing protocol. As a specimen nears its predicted point of failure, however, it could succumb to the forces exerted by the equipment earlier than expected, or in an unpredicted fashion. Thus, there is a strong desire to exert sufficient force on the specimen such that it fails (collapses), but retain sufficient control that it does so in a controlled and safe manner. When asked to describe what they do during a test, all participants but one mentioned that they look for signs of potential failures. Respondents also reported that not knowing where failures might come from mandates vigilance and, many believed, physical presence in the laboratory. In exploring the details of how local failure prediction occurs, we noticed three themes that are elaborated below.

Sensory Cues

One theme that we observed in exploring our data on failure prediction is that earthquake engineers tend to integrate multiple sensory and information streams in the process of predicting possible failures during experiments. Participants indicated that they regularly relied on multiple information sources during an experiment.

First, most of our participants reported looking at numerical or graphical displays of data from sensors and instruments on the specimen itself, and we confirmed this to be true in our observations as well. Participants looked at these data displays to ensure that all the sensors were working properly, as one participant indicated, “I want to make sure the instruments are working, that the data are coming in and being recorded.” In light of the costs in terms of both time and money associated with experiments, the importance of data integrity is not surprising. Participants also reported looking at the data to make sure the experiment was progressing as expected, and that there were no extreme anomalies. This is typically accomplished by looking at a chart of force (or stress being placed on the specimen) vs. displacement (the degree to which the specimen is moving). One participant noted that on his tests, “if we can’t explain the graphs, we stop immediately. If we get data that are surprising, but not crazy we’ll keep going.” The interesting implication here is that experiments necessarily involve some uncertainty, but there appears to be a significant and deliberate effort to mitigate risk by detecting anomalous behavior and determining whether it is within the scope of the investigation and potentially informative ("surprising") or evidence of a potential failure that might be present in the system that must be detected ("crazy").

Most participants also reported looking at the specimen to predict failures and spot potential trouble. One said that, "we are examining the specimen itself, looking around for visible signs of distress, like cracking." This is frequently combined with looking at the numerical data to supplement understanding of what is taking place. One participant provided a nice description of moving between these information sources:

I look at the force vs. displacement plot, because a change in slope on this plot means that something significant is going on. Next, you have to figure out where, how and why this is happening. You do this by walking around and looking.

Thus, we see that the integration of numerical data and visual inspection of the specimen can supplement each other.

Some participants also reported relying on hearing the test in order to predict failures. Hearing was typically integrated with viewing onscreen data and looking at the specimen.

There is also some evidence to suggest that participants with more experience in EE testing are better able to understand and integrate multiple sources, particularly auditory information. The only people who mentioned auditory information had prior experience.

Variable Likelihood of Failure

Because of their experience, we would expect faculty members and technicians to be the best-equipped individuals in a lab to detect potential failures. In some labs, only technicians are permitted to control the testing equipment, so they are always present during experiments. Faculty members have more demands on their time, but indicated the importance of their presence at tests to help predict failures. Because they frequently cannot be present for the entire test, we would expect them to be present when it was most likely that a potential failure would be spotted. We therefore asked faculty if they typically attended entire tests, and asked their students during what parts of the tests faculty were present. Responses indicated that faculty typically showed up only for the first few and last few shaking events on a specimen. This is closely related to the belief that, as we mentioned above, failures tend to occur early and late in the tests. One participant indicated, for example, that:

I'm always there for the first test on a particular specimen, because I need to train the students on the things they need to do…like making sure the test frame is not creating a physical anomaly. Students have a tendency to just roll forward without checking these things.

Similarly, many faculty indicated that they are not present for the bulk of the tests on a specimen. One participant said that she is, "not physically there watching the whole time, certainly not." Another said that, "after a while I gain confidence. I'll just show up to see what's going on and then leave."

Multiple Collocated Persons

The third and final theme we observed related to failure prediction is a reliance on multiple collocated persons, both in detecting failures and in making decisions about how to prevent them. The presence of multiple persons at any test has its origins in safety concerns. Virtually all labs have a strictly enforced safety policy stating that no testing equipment may be used when fewer than two people are present. This has the effect that multiple people are involved in making the crucial decisions about how the experiment is to move forward.

First, one senior faculty member pointed out that multiple people in the lab means that "there are different accounts of what happened, like people's reports at the scene of a car accident." Integrating these multiple human sources of information can increase the clarity and understanding of what is taking place in the test.

Second, we found countless examples of informal meetings—what one participant referred to as "powwows"—in the lab, in which the students, technicians and faculty members decided together how to proceed:

When things go awry, we tend to powwow in the lab. There are usually multiple professors, we meet in the control room with [the lab manager] and the student, and try to sort out what's going on.

This is valuable in that it allows for the integration not only of multiple perspectives on unfolding events, but also multiple forms of expertise. Multiple forms of expertise enable some specialization during the experiment. One senior technician reported that he would "often send somebody out to stand in a particular place and keep an eye on things." Another participant, a student, suggested that he likes to have "one other person around to mark cracks, take pictures, [and] take notes." Many participants we spoke with also indicated that they participate in the "powwow" and have a significant amount of influence on what takes place, but often defer final authority to the laboratory technician, who is typically the most experienced with the test equipment. It is through the collective awareness and sensitivity, combined with communication between collocated parties that potential failures can be detected and prevented during tests.

STUDY 2: A CENTRIFUGE EXPERIMENT

We focus here on a geotechnical engineering experiment that uses a centrifuge to simulate and evaluate building foundations and piles that will sit in the ground, under earthquake-like stresses. In this sort of test, a large box is filled with precisely placed layers of sand and clay to comprise a scale specimen of a field environment (see Figure 2). Video cameras and a variety of electronic sensors (strain gauges to measure structural strain, accelerometers to measure ground motion, etc.) are then placed on the specimen box for data gathering. This box is then placed on a large centrifuge and shaken while the centrifuge is spinning to simulate an earthquake. While it may seem that simply shaking the box without spinning it would suffice to simulate an earthquake, the centrifuge serves the important role of increasing gravitational forces to improve the accuracy of the simulation (Zimmie, 1995)

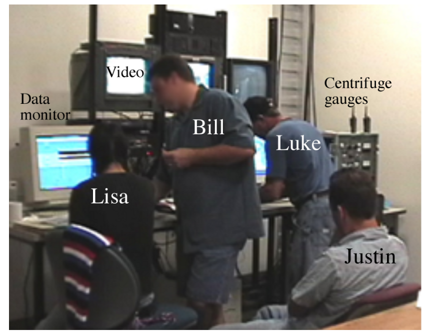
Centrifuge modeling is a particularly interesting domain for the present discussion because it is similar in important ways to the experience of remote participants. The simulation cannot take place until the specimen spinning in the centrifuge has achieved the desired force of gravity (60 G's, in the case described below). At that point, the soil box is inaccessible, and cannot be observed directly. This creates the interesting situation of researchers dependent entirely on information provided via multiple instruments—primarily video views and numerical sensor data—in order to observe and troubleshoot.

There were four people who were primarily involved with the experiment, to whom we have assigned pseudonyms as follows (see Figure 3). There were others present to observe and help but these people did not play a significant role in the episodes we present below.

- **Lisa**, an inexperienced graduate student, was the primary investigator. Her thesis was based on data gathered during our observations, and she had final say on all matters of design, procedure and analysis. Lisa had never conducted a test before, and received substantial coaching from others.
- **Bill** manages the centrifuge facility, and has been actively involved with centrifuge research since the facility's inception when he was a graduate student there. He was responsible for all technical and logistical operations.

- **Justin** was a senior doctoral student who had been involved in many centrifuge tests prior to this one. He was Lisa's primary source of advice.
- **Luke** was employed as a technician by the centrifuge facility and was responsible for controlling the centrifuge itself. He had been involved in many prior experiments, but his understanding of the research was largely confined to technical and mechanical matters.

Figure 3. The centrifuge control room



Results

Our data from the centrifuge experiment provided us with insights into how the researchers were able to reach a shared understanding when uncertainties stemming from distance arose. Despite these difficulties, the centrifuge experiment was successfully completed; in all cases where uncertainty caused work to stop, the work was eventually resumed. The examples we discuss illustrate three instances where the researchers coped with uncertainties by either obtaining more information, or re-grounding. Checking for more information generally resulted in simpler and faster resolution. Looking up readings or procedures from previous days was common, as was verifying the state of the specimen by referring to the live video feeds coming from inside the centrifuge. Water table height was measured by using a video camera aimed at a ruler physically placed in the specimen for this purpose.

In the example below, Justin and Bill have observed some strange readings from their instruments. They speculate that water leaking from one part of the specimen to another is causing several instruments to short out, which might result in the strange behavior they had observed. A discussion ensues about just what exactly is the level of the water table in the specimen, and whether they should add or remove water when they stop the centrifuge spinning at the end of the day.

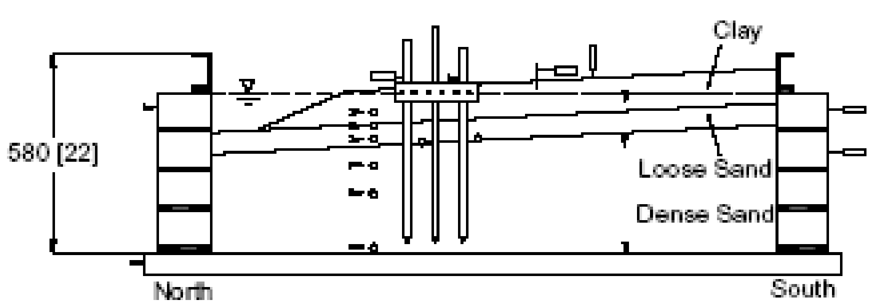
Justin: *I think it might be that there's water leaking.*

Bill: *What I was thinking was whether you'd want to change water pressure, add water, subtract water*

Justin: *When we spin down? I think it's right where we want it. (Points to video screen.) That's gotta be really close to the crest of that slope, but we should calculate the pressures. Maybe using one of the ones in the sand.*

Bill: *You want to be at 7.8, right. And you're at 8.5, so you're .7 centimeters high.*

Figure 2. Schematic side-view diagram of the soil box in a typical centrifuge test



Justin: *Yeah, I don't know why that is. Maybe that thing tipped or something. Usually we see a bit more slant on the water table too. It might be physically moved around a little.*
Bill: *Do you think it's possible that, what would it be high or low? Do you think that water table might be a little bit higher or lower than normal, Luke?*
Luke: *It shouldn't be.*
Justin: *Yeah, it's the same line. (Points to line drawn on video monitor to mark water level.)*
Luke: *Same line, same spot.*

The uncertainty about whether water leakage is responsible for instruments shorting out is answered when Bill and Justin check the line drawn on the video monitor in a previous test to mark the water level, and find that today's water level is identical.

A much more difficult situation to resolve occurred when verifying information in the control room environment and more precise communication were not enough to resolve the uncertainty that caused work to stop. In the following example, Bill, Justin, and Lisa are troubleshooting a sensor that was working intermittently. The sensor worked at lower centrifuge speeds, but as the spinning got faster it stopped providing readings. The three researchers begin by visualizing the data they had collected earlier to pinpoint where the sensor was failing:

Bill: *So what are you going to do with that one channel?*
Lisa: *Set the gain to 100 and see what happens*
Justin: *I have a feeling when we spin down it's going to come back*
Bill: *But what does that...Ok, Lisa, plot that one. Plot the one that's 10 volts. Ok, so it failed suddenly. That's what I'm wondering. Did it progress to 10 volts or did it fail suddenly?*
Justin: *Yeah, it just...fails. Where was that? About 3500? Which one was P10? (Bill walks closer to data screen)*
Lisa: *78*
Justin: *78? Go ahead and put that back in. It was right when we started spinning up from 20-40. Kinda weird, huh?*

At this point they had identified the point at which the sensor cuts out, and everyone was in agreement. However, they still need to figure out what to do about the faulty sensor. First, Justin and Bill react favorably to Lisa's suggestion of setting the gain on the faulty sensor channel to 100:

Justin: *I don't know. I guess the risk of setting it to 100 is that it'll do the same thing, which I think will happen. It's going to go to zero when we spin down, and then we set it to 100 and then spin up and then it goes to minus 10 again. I think we should spin down and terminate it, because you could be getting some crosstalk error...* (unintelligible speech).
Bill: *But you're not going to get any data. The risk of losing data is low.*
Justin: *Right, the risk of losing data is low, so I think that's a good option.*
Bill: *Gain at 100. Even if it goes out of range again, you're not going to get any data.*

Then, a mismatch between Bill's and Justin's representation of what happens when the gain is changed occurs. A brief discussion ensues. By the final line, Justin and Bill are in agreement and have returned to Lisa's original suggestion. Lisa, meanwhile, is fairly silent throughout this exchange:

Justin: *Yeah, we can adjust the noise resolution too, so that it's like it's gained to 500 except the noise will just be 5 times bigger, does that make sense? We set the D to A range from instead of -10 to 10 you set it -2 to plus 2. Then it's not going to amplify the signal its just going to give you more data in the range where you expect data*
Bill: *Actually it does amplify. It has an amplifier.*
Justin: *Oh, really, so that's why the noise is big-*

ger. I always thought the noise was 5 times bigger, but I had to apply a factor as if it was amplified at like 100 instead of 500.

Bill: *Right, it's a gain number*

Justin: *You mean the actual load? The real physical load?*

Lisa: *No, the axial load*

Justin: *The axial load? No because we're going to gain it to 100. If we gained it to 100 and then set it to -2/+2, it goes out of range.*

The above example illustrates a situation where uncertainty occurred due to a mismatch between what Bill and Justin thought would happen to their instruments if a particular change were made. Because they were discussing troubleshooting options and had not yet decided on a course of action, it was not possible for them to simply change the gain and see what happened. Instead, re-grounding occurred when Justin explained what he thought would happen, and Bill corrected him.

The centrifuge experiment provides an interesting case that approximates remote participation, to the extent that it is impossible for the researchers to interact with the specimen directly. As a result, they must rely on instruments to "remotely" monitor the experiment. As our examples show, the researchers rely on the data they receive, and their own diverse views and perspectives, when troubleshooting problems. They also are able to negotiate and discuss them together, because the views are shared. It was not important for them to be near the specimen; it was important for them to be able to discuss the information they received about the specimen and decide upon a course of action. Everybody had the same views, and the same level of responsibility for a successful outcome of the experiment.

DISCUSSION AND CONCLUSION

These studies present an interesting and potentially useful contrast in people's perceptions of their information needs and, by extension, their grounding needs. When confronted with the possibility of remote participation in their research, the engineers we spoke with in the first study were concerned that they would be unable to detect and respond to potential failures or errors because they would not have enough information about what was taking place in the experiment. In the second study, on the other hand, information was significantly constrained due to the spinning of the centrifuge. Failure prediction was still possible, however. What seemed to matter in this case was not having access to vast amounts of video or sensor data. To be sure, these were useful. But they were not always consistent and did not offer a complete explanation of what was taking place. Rather, what was most important in resolving these scenarios was access to persons with relevant experience and diverse perspectives. It was through interpretation and discussion of whatever information was available that conflicts were resolved and common ground was re-established.

One key question from this case comparison is how the second study can inform the first. In other words, what lessons does the centrifuge experiment hold for remote participation in laboratory experiments more broadly. On the one hand, there are many possible lessons. The centrifuge, after all, is an extreme case of remote participation in that all participants are remote. On the other hand, this trait also creates an equality among participants that will rarely be replicated in other laboratory settings, where at least some participants are likely to be local and able to interact with and directly manipulate the specimen.

How then do we derive general lessons for teleparticipation from the centrifuge case? One thing that was particularly clear during the centrifuge case was that having input from many sources helped resolve issues and problems in ways that enabled the experiment to move forward. We therefore argue first that one aim of teleparticipation be to allow remote participants to contribute their diverse viewpoints. Second, in cases where there are both local and remote participants, we argue that teleparticipation technologies themselves can be used to increase the diversity of viewpoints that are represented.

Put more formally, it was agreed on by our participants that having multiple observers increases the likelihood that an impending failure can be detected. Imagine an observer who has a certain probability of detecting the cues to an impending failure given that a failure is imminent. We would denote this probability as $P(D|F)$ or the probability of Detection given Failure. If $P(D|F)$=0.5, then in the presence of impending failure, this observer would be able to detect the cues 50% of the time. We can calculate the probability that at least one of n observers will detect an impending failure as:

$$P(D|F)=1-(1-P(D_1|F))...(1-P(D_n|F)) \quad (1)$$

assuming that all observers are statistically independent. This means that with two detectors, one with a probability 0.5 and one with a probability of 0.4 of correctly predicting an impending failure, the probability that at least one would detect the impending failure is

$$P(D|F)=1-(1-0.5)(1-0.4)=1-(0.5*0.6)=0.7 \quad (2)$$

Further, with the addition of any statistically independent detector, i with a $P(D_1|F) > 0$, the global detection probability will increase. The false alarm rate will also increase, of course, but such an increase would likely be tolerated given the high costs associated with a missed detection. This is strongly akin to Weick (1995)'s observations on the value of "requisite variety" in an organization's repertory of beliefs:

The greater the variety of beliefs in a repertoire, the more fully should any situation be seen, the more solutions should be identified and the more likely it should be that someone knows a great deal about what is happening. (Weick, 1995)

At first glance, this would appear to indicate that each additional observer who is physically present at a test would increase the global probability of detecting an impending failure. However, our analyses suggest that individuals who are physically co-present during a test are likely to have positively correlated detection probabilities. That is, because they share the same sensory-rich environment and are able to interact with one another, they are likely to rely on similar bits of evidence in making their judgments. In addition, there are psychological and sociological processes, such as groupthink (Wason, 1960) and confirmation bias (Janis, 1972), that may lead their judgments to be correlated. The more highly correlated the individual detection performances are, the lower the benefit of additional observers becomes (such that, if all observers were perfectly correlated, the likelihood of at least one individual detecting an impending failure is no higher than best detector's individual probability).

While it may be natural for people to think of remote participation facilities in terms of providing a low fidelity imitation of the environment that individuals experience when they are physically present, such facilities may also be re-conceptualized as environments in which benefits may be garnered through a different representation of the problem. In certain contexts, a "beyond being there" approach, in which remote observation tools are designed to complement the information that is available to those who are attending a test, could theoretically allow remote participants to play the role of less correlated observers—thereby improving global detection performance.

Birnholtz et al. (2005) found that remote participants who were not involved in decision-making did not need high-bandwidth interaction capacity to participate in the way that they wanted to. We suggest that it might be possible for these same people play "grounding support" roles—that is, exploit the fact that they're not involved in decision making and make them inputs into decision making. To do so, remote participants would have to be able use information that physically present observers cannot or do not use. The effect would be not only an increase in failure detection capacity, but also a potential increase in enthusiasm for and adoption of remote participation technologies as a result of this new capacity.

One example would be to implement filters that highlight features of interest on streaming video. Physically present observers are not likely to rely on streaming video given that they can directly observe the specimen in front of them. For example, if remote participants could view video of a live test with overlays indicating visual features that are difficult to discern in person, such as out-of-reach portions of a specimen, they would be able to offer more statistically independent observations than additional physically present observers could.

It would, of course, be possible to provide similar video views and filters to a co-present observer, but we contend that physically present observers will already be occupied by a great deal of higher-fidelity sensory information, making it difficult to attend to additional views, while a remote participant would be more likely to have attention resources to spare. Additionally, while local participants could choose the role they play, remote participants do not have that freedom, and may best be thought of as either having no active role or a constrained active role.

This presents something of a paradox for theories of common ground. The prevailing wisdom is that more information is better, and that shared information supports reaching a shared understanding of of a situation. However, diverse perspectives could actually support better decision-making. This follows from a stream of recent work suggesting that optimizing for the very best and most accurate and most realistic information is not always appropriate, be it in thinking about excuses for not answering one's phone (Aoki and Woodruff, 2005), ambiguity in design (Boehner and Hancock, 2006), or coupling a video view to movement (Birnholtz et al., 2008).

It is also true, however, that adding non-correlated remote observers increases the potential amount of information confronting the co-present research team (Birnholtz and Horn, 2007). In addition to providing remote participants with different views, then, another implication of this work is the need for systems to aid in the integration and interpretation of the input provided by multiple human observers. In some important ways this is akin to research currently underway in the area of sensor and data fusion (Bisantz et al., 1999), and may benefit from those techniques. Future work in this area should extend beyond case studies, to better map out the dimensions of the space of modes of participation, and more rigorously define the grounding needs and constraints for situations where remote participants contribute diverse perspectives to the decision-making process.

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KEY TERMS

Beyond Being There: Exploiting unique attributes of technology to enable experiences that would not be possible in face-to-face environments, as opposed to using technology in attempting to replicate the experience of being there.

Collaboratory: A set of technologies and resources for connecting geographically disparate people, research facilities/apparatus, and data for the purposes of education and research.

Cyberinfrastructure: The set of shared computing, software and networking resources that enable the transformative use of novel technologies to enable discovery and novel modes of collaboration.

Common Ground: A state of mutual understanding among conversational participants about what it is that is being discussed

Grounding: The conversational process of negotiationg a shared understanding among multiple participants about what is being discussed.

Requisite Variety: The notion that a certain amount of diversity in viewpoints and perspectives is required for groups and organizations to address complex problems as they emerge.

Teleparticipation: The involvement of persons who are not physically present in a physical activity or event taking place in the real world

ENDNOTE

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