Warm Fronts and High Pressure Systems: Overcoming Geographic Dispersion in a Meteorological Cyberinfrastructure Project

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Abstract

Linked Environments for Atmospheric Discovery (LEAD) is a US National Science Foundation multi-disciplinary project designing cyberinfrastructure for mesoscale meteorology. This ethnographic case study, supplemented with survey data, illustrates the unique management challenges faced by large, geographically-dispersed teams using distance technologies. Like many cyberinfrastructure development projects, LEAD had no common institutional affiliation, simply shared funding. We explore how participants struggled to blend people and expertise across multiple institutions. LEAD relied heavily on technologies to support interaction, but these overshadowed the true core of their success: the team members' collaboration history and interpersonal skills. Nevertheless, competing institutional goals and agendas constantly aggravated the burden of keeping the project team motivated and aligned. Our results suggest that the fate of cyberinfrastructure projects, unlike those in centrally managed corporations or loosely coupled collaboratories, may rely more on members' willingness to exert the effort required to build and maintain long-distance relationships.

1. Introduction

Linked Environments for Atmospheric Discovery (LEAD) is an initiative to build a comprehensive national cyberinfrastructure for mesoscale meteorology that will help students, faculty, research scientists, and operational practitioners better understand and predict severe weather events [13]. Cyberinfrastructure (CI) is defined as a coordinated framework of technology and human expertise intended to support scientific discovery, particularly research requiring high-performance computing, large quantities of data, or distance collaboration. LEAD will provide a complete information technology infrastructure that will allow people to run atmospheric models and other tools in much more realistic, real-time settings than are now possible. The high-end capabilities of LEAD are targeted principally toward the meteorological higher education and operations research communities but will also be a resource for teachers of pre-college students.

In the broader picture of the US national scientific research agenda, the LEAD project is one of several initiatives pursuing the potential of CI to support science and engineering. The National Science Foundation (NSF) and their US and international partners see CI as critical to the future of research [3, 10] and have invested in large technology enterprises designed to transform science by making resources accessible to more people and helping those people connect with each other. These projects are huge, multidisciplinary, and geographically distributed. Even though research in computer-supported, cooperative work and virtual organizations have improved the quality of the tools and strategies for distance collaboration, we find that large CI projects face some unique challenges due to their spread across domains and institutions.

1.1. The "climate" of CI development

Because CI research and development teams need to be multidisciplinary to develop computing technologies that will support specific domains of scientific research, CI projects often require distance collaboration. These projects typically bring domain scientists together with computer scientists or other technology specialists, but rarely are these collaborators situated at the same institution. In addition, though most domain scientists use computers for their work, the language of computer science, particularly that associated with high-performance computing and networked systems, is unfamiliar and arcane. These collaborators must find ways to communicate across the barriers associated with specialization [7, 9]. Consequently, not only do the participants have to become conversant in an unfamiliar topic, but they also have to negotiate their work at a distance, often across multiple time zones. Multi-institutional projects often face

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substantial coordination costs that can detract from their collaboration although regular face-to-face interaction lessens the damage [5].

These cross-disciplinary challenges are not new and the issue of integrating multiple perspectives on product development teams has been recognized for many years [16]. However, CI projects may be unwieldy in ways that previous studies have not emphasized [14]. Existing research has focused on virtual teams with small numbers of people at each site [17] or with a large core group and small satellite members [8]. In contrast, CI projects such as LEAD involve large numbers of people at many sites, each bringing centrally important expertise to the project. These people may be committed to multiple projects and have additional research goals that are independent of the CI project. When resolving role conflicts and commitments, project members may favor responsibilities to the larger institution where they work, not a project funding a fraction of their time [2].

Unlike project teams employed by a single institution, there is no central authority resolving differences of opinion or mandating deadlines. In fact, because each researcher is typically from only one domain and does not assume expertise about the needs of the other facets of the project, authority and expertise cannot be centralized. The leaders of these projects are generally colleagues, so there is no hierarchy or reporting structure that makes decision-making rules clear. Although the collaborators are affiliated by a common goal and they are interdependent in order to achieve that goal, the projects have neither financial structures nor other incentives to hold participants accountable to those at other sites. Of course, it is in the project's interest for everyone to support each other's work and aim to reach consensus, but even so, the "right thing to do" is not always self evident nor is it enforceable.

At the same time, CI projects are not as flexible as collaboratories. Collaboratories, while large and distributed, form to share resources and trade ideas, but they do not have the degree of interdependence of CI projects [6]. Collaboratory work is better characterized as "loosely coupled"—requiring awareness of colleagues' activities but proceeding in parallel [19]. CI projects are more tightly coupled; work requires notification, understanding, and negotiation to complete. Thus, relatively little is understood about how virtual teams organize on projects of this scope and complexity [14].

In this paper, we present a case study of LEAD as an illustration of the challenges faced by projects at the forefront of the CI movement. Our research objective was to explore the difficulties presented by these structural aspects of CI projects, in the context of LEAD. Specifically, what are the challenges associated with a large, multi-disciplinary, multi-institution project that is tightly coupled yet not centrally administered? Moreover, how do such projects overcome these challenges? What we find is that technology does little to overcome—and may aggravate—the fundamental organizational and relational challenges associated with a project of this type. After a brief description of our research methods and analysis, we introduce the project and outline its history. Next, we assert that large-scale, group-to-group collaborations that involve large teams at multiple sites face greater difficulties at achieving coherence of goals and priorities. We demonstrate that the project's successes may stem less from supporting technologies and more from the team members' interpersonal skills and prior and ongoing history of collaboration that prompted them to put in the extra effort to maintain coherence. Their accomplishments may in fact be *despite* the technology they used for collaboration.

2. Research methods

LEAD is a multidisciplinary collaboration among nine geographically distributed institutions, involving more than 100 participants (researchers, educators, students, and technical staff). This case study is the product of twelve months of close observations of and extensive interviews with the LEAD project team and a survey administered to the active members of the research and development team.

2.1. Participants

Participants in this case study included all people affiliated with the LEAD project. Our interviews included 25 members of the research and development team, selected to represent multiple institutions and roles. The survey sample was derived from the members of the main project listserv and the project's annual report. We asked the Principal Investigators (PIs) on the project to confirm whether the participants identified at their institutions were appropriate to include in the survey sample. (Many were only peripherally involved, funded for as little as 10% of their time.) We sent the survey to 63 members of the team. We received 44 responses (70% response rate). A scan of the list suggests that those who did not respond were those who were less active on the project at the time of the survey. The respondents were 73% male. PIs provided 36% of the responses, 45% of respondents were staff members (research, programming, or administrative), and the remainder of the respondents were post-docs, students (undergraduate and graduate), and affiliates. Approximately half of the sample had PhD degrees.

2.2. Qualitative data collection

We participated in project-related meetings (video, telephone, and face-to-face) and conducted semi-structured interviews. We have logged more than 130 hours observing meetings. We visited six of the nine participating

institutions in person, spending more than 15 days on site, viewing each site's resources and work environment and interviewing members of the project team.

The semi-structured interviews concerned the history of the project and each participant's involvement in the project, the project's collaboration and coordination requirements, approaches and technologies for accomplishing collaborative work, issues of multidisciplinary collaboration, and the project's challenges and successes. The mean length was 67 minutes. Most interviews were audio recorded, after which each interview was reviewed and summarized to capture the major topics covered by the interview questions, including verbatim quotations.

We also collected documents from meetings, e-mail exchanges, and the project's website, as well as formal status reports and published articles about the project. These documents helped us to frame the history and organizational structure of the project as well as the current and future objectives of the effort.

2.3. Analysis of qualitative data

With the intent of developing a survey to capture the broader sentiment among the LEAD team, we reviewed the interviews and our fieldnotes for prominent themes about what aspects of their collaboration were effective and ineffective, including their perceptions of the technologies and processes used to support a multi-institution project. To do this, we used an inductive, data-driven thematic analysis method as described by Boyatzis [4]. The issues we extracted were those that surfaced repeatedly in the interviews or had been observed multiple times during our participation in meetings.

2.4. Survey instrument

Survey questions were based on these issues and included both Likert-style, multiple-choice and open-ended questions. The 43 survey questions covered aspects of their collaborative work, including:

- meetings (e.g., "Indicate your level of agreement with the following statement: We have too many meetings.")
- technology (e.g., "How often do you use the shared repositories for LEAD, such as CVS and LEADzilla?")
- coordination (e.g., "To what extent is coordinating work between institutions a problem on the LEAD project?")
- communication (e.g., rating the helpfulness of or their satisfaction with each communication method)
- problem solving (e.g., "To what extent is integrating components a problem on the LEAD project?")
- interpersonal interaction (e.g., "How present on the project is each of the following items?" Items included: Consensus on priorities, Comfortable work environment, Trust)

We also asked for basic information about prior experience with collaborative projects (e.g., number of multidisciplinary and multi-institution projects), roles, education, and gender. The two open-ended questions were "If you could fix one thing about how the LEAD team works together, what would it be?" and "What is LEAD's biggest success and why?" (The complete survey is available by request from the authors.) We informally piloted the questions with members of the team before administering the survey. The survey was administered six months after we began our study. Participants were contacted by e-mail, and they accessed the survey on the Web using Survey Monkey.

2.5. Survey analysis

The content and conclusions of this case study are derived from the results of the survey as well as the qualitative analysis conducted throughout the observation period. In the survey results, we examined the responses for patterns that could be general indicators of opinions across the team. We then returned to the fieldnotes and interviews to add contextual depth to these numbers and patterns. Combining these materials, we derived three major themes related to collaboration and the use of technology [4]. Within these themes, we looked for evidence of what mechanisms might be operating to determine the team's effectiveness (or lack thereof) in these areas, repeatedly searching for evidence that might generalize to similar contexts. We describe our conclusions after we provide some context for the project. We use the survey results as illustrative descriptive statistics, not to assert statistical relationships.

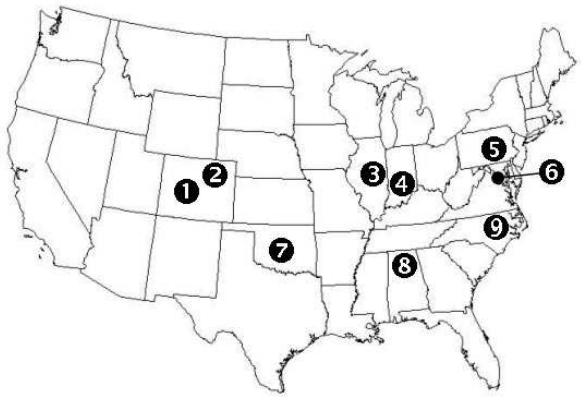
3. Project background

Although weather forecasting appears to be technologically sophisticated, with equipment that offers up-to-the-minute analysis and prediction, the field is burdened by static information technology systems [13]. The tools used for observation of weather phenomena are not designed to dynamically respond to events as they happen. Moreover, the data processing capabilities needed to analyze weather patterns are enormous. The computational power needed to accommodate the data formats and complex numerical models is unavailable to all but the most sophisticated users of computer technology.

Recognizing this, a small group of academic researchers came together to propose an unprecedented system that would allow people to track, understand, and predict weather in real-time, adapting dynamically as the weather changes. They built a team of people who could address the diverse needs of such a complex project. The group included atmospheric scientists and educators,

computer science researchers, and software engineers, balancing expertise in atmospheric science and computer technology. In 2003, their project was funded through the NSF's Information Technology Research (ITR) program, which provides long-term support for high-risk, innovative IT projects designed to have an impact on other science and engineering fields.

The project required extensive fundamental computer science research, as well as robust software development, to be sustained over the five years of the project. Even though this work was focused on IT, it needed substantial contributions from the atmospheric scientists and educators on the project. To manage this, responsibility was initially divided into "thrust groups" that focused on crucial aspects of the overall system—meteorology, data, workflow orchestration, and tools—plus cross-cutting groups for grid & web services test beds, and education & outreach. Each group included members from each discipline and each institution concerned with that part of the system.



❶ Univ. Corporation for Atmospheric Research (UCAR), Boulder, Colorado, Unidata Program
6 core of 16 people
❷ Colorado State Univ., Ft. Collins, Electrical & Computer Engin.
3 people
❸ Univ. of Illinois, Urbana-Champaign, National Center for Supercomputing Applications & Atmospheric Sciences
5 core of 13 people
❹ Indiana Univ., Bloomington, Computer Science
5 core of 19 people
❺ Millersville Univ., Pennsylvania, Earth Sciences
3 core of 12 people
❻ Howard Univ., Washington, DC, Physics & Astronomy
3 core of 8 people
❼ Univ. of Oklahoma, Norman, Meteorology
6 core of 14 people
❽ Univ. of Alabama, Huntsville, Computer Science
6 core of 14 people
❾ Univ. of North Carolina, Chapel Hill, Computer Science
3 core of 8 people

Figure 1. The geographic and disciplinary distribution of the LEAD team

Over time, the team encountered several challenges inherent in the structure of their charge. These challenges combined to make it more difficult for them to achieve coherence across the multiple institutions involved in the project. On the surface, the project team's interaction was indeed successful. But this success was threatened by undercurrents of tension that grew out of the institutional differences and coordination costs that could not be avoided. In the following sections, we first present the self-evident success indicators—or "warm front"—of the project, then we discuss the "high pressure systems" that jeopardized their success.

4. Warm fronts: Early successes

The LEAD project's initial and perhaps most obvious challenge was how to organize a large, multidisciplinary effort involving nine geographically distributed institutions and more than 100 scientists, students, and technical staff. (See Figure 1 for a summary of the project team's scope.) Fortunately, many in the team were already used to such arrangements. According to our survey, only 16% of respondents had never participated in a multidisciplinary project prior to LEAD, and 50% had participated in three or more multidisciplinary projects. Similarly, only 18% had never been involved with a project at multiple institutions, and 52% had been part of three or more multi-institution projects. Though prior experience with the logistics of this kind of project was an asset, creating team cohesion and multidisciplinary understanding at a distance still had to be renegotiated for this project. In particular, the members had to learn enough about each other's methodologies, vocabularies, and analytical approaches to understand their development options and agree about how to accomplish their goals. We observed that the team pursued several effective strategies for promoting understanding across institutions and disciplines. We describe three of these strategies in the following sections: substantial cross-disciplinary exchange, extensive interaction with and without communication technologies, and the leveraging of prior collaboration experience with each other.

4.1. Communicating across disciplines

The LEAD project was at the cutting edge of both meteorology and computer science, which meant that every team member needed to learn and work with advanced concepts from another discipline. This might have been the greatest hurdle in the project, but it appeared to be quite manageable for them. In interviews and informal conversations, project members reiterated how effectively and patiently each discipline had been with the other, taking time to explain concepts or even arranging

educational videoconferences to explain fundamental technologies or topics. Thus, it is not surprising that nearly 90% of survey respondents felt that there was an understanding of terminology from other disciplines.

Project members recognized a potential institutional divide on top of domain differences, so by arranging the team into thrust groups (see section 3) they could incorporate multiple viewpoints as they sorted out their options and made decisions. Over time the team discovered that other working sub-groups needed to interact on a regular basis, so they formed a portal thrust group while the activity of the tools group faded.

Because most of the participating institutions held either computer science or meteorology expertise, but not both, another way of bridging between institutions was the exchange of people from one to another. For example, one person with an electrical engineering background initially worked with meteorological applications at the University of Oklahoma. Early in the project he moved to Indiana University to join their computer science group. Many people realized what an effective translator he had become due to his knowledge of operations in both meteorology and computer science. Consequently, other people on the project made a point of spending several concentrated days at another site from time to time. This exchange is evocative of other research on distributed teams that found that swapping people before crucial multi-site meetings could help with translation and interpretation between sites [22].

Thus, the LEAD team successfully bridged disciplinary differences by encouraging educational exchange. They structured the project to require interaction across disciplines and made sure that people worked with each other in person on a regular basis. These practices helped people feel comfortable about asking questions and seeking input.

4.2. Bridging spatial and temporal distances with technology

The LEAD project was set up to support distance collaboration with a variety of communication technologies, supplemented with face-to-face meetings. These technologies included multipoint videoconferencing, teleconferences, e-mail listservs, and a project website for sharing documentation. Almost all of the people on the project had commitments to projects other than LEAD, and most of the PIs had heavily booked schedules, so both synchronous and asynchronous technologies were necessary for moving the project forward.

Other than day-to-day interaction among collocated team members, the bulk of synchronous communication happened in some type of scheduled meeting. The project meetings used multipoint videoconferencing technology primarily, teleconferences less frequently, and face-to-face gatherings periodically. The multipoint videoconferencing used by LEAD was the Access Grid (AG, accessgrid.org), an Internet-based means of group-to-group videoconferencing that brings together multiple sites in the same virtual venue. Teleconferencing was primarily used by the PIs for a weekly meeting, and occasionally it was used if videoconferencing was not available. Where AG apparently excelled was helping people get to know others on the project. Even though the video was small and low-resolution, people could fairly easily see who was talking. Teleconferencing was a particularly satisfying way of engaging other people in discussion, producing fewer complaints than videoconferencing. This is consistent with research finding that video and audio-only connections can enable work of the same quality as work produced in face-to-face meetings—the work simply requires some process adaptations which take extra time [18].

The LEAD project was notable for the heavy use of the e-mail listservs. One PI admitted in an interview, "This project generates more e-mail than any *two* projects I've worked on." Among respondents, 38% felt that information overload was a problem or a serious problem, and this was compounded by the already existent overload that is common with e-mail. (When asked to describe what he did at work, one meteorologist said, "I answer e-mail all day.") The use of listservs, however, had an additional problem, which is that a message cast out to many did not necessarily draw a response from those who were expected to reply. In interviews, some people said they worried that their carefully crafted or high priority messages were falling by the wayside. In the survey, however, 38% indicated that they felt others responded adequately to the written materials they prepared and distributed while 28% did not. When responses were thin, people sometimes needed to send a more directed message. This problem was apparently not fatal, as 68% agreed that it was easy to get answers from the right people when they needed to.

An all-hands meeting was intended to bring the entire team to one location in order to take stock of their progress, chart future objectives, and resolve complex issues, but usually several representatives attended from each institution while others stayed home. In interviews, many people remarked how productive face-to-face meetings were, particularly because people focused intently on the task at hand for the limited time they had together. Indeed, research suggests that distributed teams perform better when meeting formats accommodate the complexity of the task at hand [15]. In an interview, one PI explained, "Face-to-face meetings are most useful by far. I think we get more done on the times when we actually get together.… We just hammer though the topics until we are done." Unfortunately, face-to-face meetings were typically costly, even when held at a central location, since many people had to fly or drive long distances and stay at a hotel.

In the survey, we asked participants to indicate how helpful each of the forms of communication were for them. Eighty-eight percent of respondents indicated that direct e-mails were helpful or very helpful, not surprisingly followed by face-to-face meetings (78%). Presumably the only disadvantage of face-to-face meetings was the time involved. For interaction that required synchronous conversation, video and telephone conferencing filled the gaps. The project leaders certainly erred on the side of promoting large amounts of interaction, and this ensured that information was widely available and shared.

4.3. Leveraging prior collaborations

Strikingly, the team appeared to interact with the ease of friends or coworkers who knew each other well, and differences were handled amicably. Several of the experienced PIs suggested that this was not a typical situation, having participated in or reviewed multi-disciplinary or distributed project teams that worked together as if they barely knew each other. Camaraderie was evident at any virtual or face-to-face gathering. People joked or chatted about the latest interesting weather phenomenon. Even by e-mail, people would exchange silly remarks and teases. Prior friendships such as these have been found to improve performance in groups by increasing both commitment and cooperation [11], and even some prior experience improves communication effectiveness via computer-mediated channels, particularly by improving openness and trust [1]. By and large, those surveyed agreed that they felt comfortable sharing ideas and feelings about work with their local colleagues, and 77% felt comfortable with their remote LEAD colleagues.

The unofficial norm was that major decisions about the functionality of the system were made by consensus, recognizing the value of all perspectives. In interviews, project members emphasized the high degree of respectful interaction across disciplines. One of the PIs suggested that the reason there was such a good working relationship among the team members and across the institutions is that many of them had collaborated with each other before, and they would see each other at conferences and meetings for other projects. In fact, 38% were involved in projects other than LEAD with their LEAD colleagues at other sites. As this PI described it: "One reason I think this project works really well is that almost everybody in the project has known each other a long, long time." The survey results reinforced this opinion. Ultimately, 79% of survey respondents believed that trust was present among the group at least somewhat if not more. Also, 68% of survey respondents felt that people listened to what they had to say about the project. Even those that had not worked with others on the team before remarked that they felt recognized and welcomed for their unique expertise. In fact, when asked to identify the project's greatest success, the most common answer was that the group had been so effective at working together as a team. Thus, a positive history of working together set the stage for the entire group to share goodwill and camaraderie.

5. High pressure systems: The struggle for coherence

Unfortunately, these positive strategies were not without problems. Cross institutional interaction and agreement was not as effective as it might have been. Coordinating was difficult, and sometimes technology seemed to get in the way. Ultimately, a lack of technologies sufficient for supporting decision making, combined with an organizational structure without a hierarchy of decision-making authority, made requirements and priorities very hard to identify, select, and pursue. Each of these weaknesses undermined the project's coherence and increased individual concerns. We discuss this flip side of the three successful strategies in the following sections.

5.1. Disconnects across groups

Thrust groups were the dominant structure for promoting multidisciplinary exchange. Although thrust groups did encourage people to work together across institutions, survey respondents agreed that working together smoothly was still a problem. For example, 60% of survey respondents admitted that coordinating work between institutions was a problem. In the interviews, people suggested that the thrust groups were not suited to the way the work was getting done. In the survey, about half of the team felt that the division by thrust groups was effective. Most of the remainder thought that a better way of integrating the team would be to divide instead according to those working on features of the software as perceived by the end user, specifically to be more integrative. As one person remarked, "Sometimes I believe that even through all of the e-mails and [video] sessions, there is still a feeling of alienation between the groups due to the different interests and goals of each." Some suggested that they should just acknowledge the reality of institutional differences and distribute tasks according to institutional expertise. These concerns are consistent with research finding that distributed teams tend to have greater problems with conflict and trust when the team has distinct subgroups at different geographic locations [21].

Another way that disciplinary differences surfaced was in the use of common terms. For example, a software "release" was a much bigger milestone to the computer scientists than the meteorologists, so the use of the word alarmed the computer scientists. In the struggle to find better ways to talk about their project, the team changed

the language they used, and this added to the confusion and frustration. One person recalled, "We sort of changed things a lot along the way. That's sometimes hard to keep up with. We started with 'prototypes,' and then we went into the 'canonical problems,' and then we went back to the 'prototypes.' And then now it is 'mini-LEAD'… All this time we were kind of working on something, and then it seems like that goes away." In some ways, the project team had come full circle, back to the task of understanding each other across the divides of discipline and geography.

5.2. Meeting without being there

In general, meetings were complex, both in terms of frequency and content. Moreover, participants were located in three time zones, making some meeting times inconvenient or impossible for at least one group. Coordinating ad hoc meetings, often handled by e-mail, was complicated by the PIs' frequent travel and large e-mail volume, making them slow to respond to scheduling requests. About 46% of survey respondents felt that coordinating meetings was a problem to some degree. In the first year of the project, most of the thrust groups met regularly on AG at least every two weeks, so some people in multiple thrust groups were overwhelmed with the volume. After about a year, AG meetings were condensed to weekly, 2-hour "all hands" sessions covering general content, with thrust groups meeting monthly or as needed.

Given the team's dependence on AG, it introduced some difficulties. Videoconferencing has known technological disadvantages, including video capture setups inadequately supported by room design [20], unsuitable video size and quality [17], and poor indicators of technical problems [14]. Meeting time was often wasted trying to get all the technology working. Another weakness of AG was the sound quality. Not only was the software running the audio transmission very unstable, but also within a site the microphones were unable to adapt to the varying volumes and distance of different participants in the room, making one person barely audible and another overwhelmingly loud. Dissatisfaction was 31% compared to just 9% dissatisfied with teleconference sound quality.

One particular problem of AG meetings was their inability to keep team members actively participating. To some extent, this appeared to be due to the content of the meetings because more general meetings were not as relevant to as many people at any given time. More than 65% of respondents indicated that there was a need to have AG meetings more focused on specific agenda items. However, we also observed that many people were multitasking—absorbed with their laptop computers—and not always alert or responsive to the discussion. Even though multitasking is prevalent in many settings, switching between tasks causes a delay as people reorient from one task to another, and such lags increase when a task is more complex [23]. We observed that those not actively part of a discussion were slow to join the conversation or respond to a question. One PI asserted, "I think Access Grid meetings are less useful, at least in the form they have been taking. It is hard to get people engaged in the Access Grid. They will be there. Their bodies will be there, but *mentally* they are somewhere else." We speculate that the feeling of distance inherent in such meetings (compared to face-to-face meetings) made people comfortable with not giving their full attention, whereas such behavior would have been considerably more obvious when collocated.

5.3. Killing with kindness

Some participants questioned whether the upbeat and collegial tone within the team masked some underlying disagreements that needed to be resolved. Based on our observations and conversations with members of the team, it seemed that more conflict and disagreement surfaced within disciplines than between them. For example, in computer science and engineering, experienced people with different approaches to a task or problem advocated for their perspective. This was complicated by the structure of the project administration: multiple PIs, each experts in their field with prior experience leading research projects. The PI who brought the team together was an enthusiastic, admired leader, well versed in some of the most high-tech aspects of weather modeling and analysis. Nevertheless, he was aware that he was not the authority on many of the technical decisions that had to be made and instead tended to facilitate consensus among the experts on the team. Because the rest of the PIs were of equal status, this meant that most technical decisions required negotiation and the integration of multiple, often differing perspectives. Some team members were concerned that those who were soft-spoken or less assertive were unable to express their opinions in these situations. One remarked, "Technical discussions seem to rely too much on a single person's point of view. There is a fear of stating one's opinions when they go against the grain." Unfortunately, research suggests that groups that adopt a conflict-avoidance style tend to be less effective at decision making, even when the decision does not involve conflict [12].

Consequently, as the project moved toward establishing standards and connecting components of the software, team members saw the need for a single technical leader who could supervise these decisions. Although 34% felt that technical leadership was very present, another 29% felt that technical leadership was not very or not at all present. When asked what one thing about the project they would like to fix, many responses focused on the need for a full-time technical coordinator, someone with "both the

responsibility and authority to make decisions" and enforce them. This gap had strong effects on the establishment of requirements and standards and on the selection and enforcement of priorities, especially the competing priorities of research and development.

The research versus development problem was endemic to NSF's ITR program funding, which expected both research and new products to emerge from their support. Research creates long-term, fundamental knowledge while development fills short-term implementation needs, so they do not easily happen together. For LEAD, the freedom of research was necessary for the computer scientists yet the meteorologists and software engineers focused on the development of a robust, reliable tool. Acknowledging these dual goals, the project team struggled to agree on the timing and prioritization of the research and development processes.

Although 60% of respondents believed that there was at least some degree of consensus about priorities, also 62% identified achieving shared priorities as at least somewhat of a problem, if not more. In addition, fully 50% of the survey respondents agreed that the LEAD team changed short-term priorities too often. This issue of priorities was raised by many people. Again, when asked about fixing one aspect of how the team worked together, replies included: "Set goals and not change plans and direction as often," "Rewrite immediate priorities and…stick to them," and "A bit more focus and constant direction."

In sum, behind the cross-disciplinary interaction, frequent communication, and good cheer were more turbulent conditions. Although the team members held frequent meetings and e-mail exchanges and listened to each other, the team lacked coherence. Integration of components (and opinions) across institutions was not easy, and people were pulled in multiple directions. The poor quality of distance communication technologies did little to narrow those gaps and engage people across sites. Finally, the lack of an authority structure meant that decisions, standards, and priorities went unresolved or were not clearly resolved.

6. Conclusion: Weathering the odds

Although the LEAD project was an immense challenge, both in terms of the outcomes it would generate and the logistics to be negotiated, the team was enthusiastic about achieving those goals. Participants could relate to the vision of this dynamic, adaptable tool for meteorological research and forecasting, and they developed rapport among the team as if they were not separated by so much distance. How was it then that the LEAD project team could be so effective yet also thwarted in the same aspects of its collaboration? A review of the circumstances offers some clues to their effectiveness in each of the three areas we have described. Table 1 summarizes these differences.

First, the effectiveness with which the project team integrated multidisciplinary and multi-institutional interests depended on the overlap of understanding that they could create. They were most successful by demonstrating their respect for each other and their willingness to explain. Thrust groups and the exchange of people between institutions were two ways of accomplishing this. On the other hand, each institution embodied a particular discipline and the perspective associated with that discipline, thereby reinforcing differences between the groups. Where these specialties were clearly different, they could articulate questions for each other, but where they overlapped, there was greater risk of misunderstanding and missing the nuances of terminology.

Second, the value of regularly using communication technologies for coordinating work relied on the appropriateness of the technologies within their context, specifically a setting in which time and funding was scarce. The project team and its leaders made communication a priority and found multiple ways to support that end. However, the technologies they used were often

Table 1. Factors influencing the effectiveness of large, multi-site CI projects

	Enablers	Obstacles
1. Multidisciplinary Integration	• Respect and patience across disciplines • Multi-institutional "thrust groups" • Exchange of people between sites	• Overlap of institution with discipline and stakeholder perspective, reinforcing turf issues • Magnitude of comprehending the nuances of another discipline
2. Communication Technologies	• Heavy use of videoconferencing and e-mail listservs • Regular face-to-face meetings	• Frustration with communication technology • Multiple commitments (almost no full-time team members)
3. Consensus Orientation	• Prior experience working with each other • Broad input to decisions	• Emerging technologies with no single standard or solution • Limited budgets (doing too much with too little) • Competing local goals without an authority structure
Overarching Themes	• *Shared vision* • *Spoken commitment to broad inclusion*	• *No umbrella organization—just a virtual umbrella* • *Scarcity of needed time and resources for learning, understanding, meeting while keeping up progress*
Bottom Line	*Simulating a unified organization*	*Lacking the structure or resources to integrate goals*

frustrating, and the disengagement they allowed (as compared to meeting in one location) let team members be distracted by their multiple competing commitments.

Third, the team leadership's orientation toward building consensus made sense given the complexities involved. This was helped by their work history with each other and an open invitation to give input. However, the nature of decisions on the project were hampered by tremendous uncertainty—emerging technologies, few standards, many possible solutions—and budgetary constraints that limited investment in multiple options. Moreover, each site had commitments to its local institutional goals, of which LEAD was a component part, so when goals conflicted, there was no one with the authority to choose one way or another.

Thus, the overarching difficulties faced by this project —represented in these three areas—was that being a large-scale project involving many semi-independent but also interdependent groups at multiple sites made it more difficult for the project to achieve coherence. Such issues are not typically present for distributed teams that are unified by a single corporate mandate. Also, large-scale collaboratories, such as those who interact across a network designed for data sharing, typically do not face the multidisciplinary boundary-crossing nor the tight coupling associated with building a robust software product. In addition, as with many large grant-funded projects, money and resources were tight. Almost every person on the project was part-time so rarely had the time and resources necessary to keep up with the project's demands for learning new things. What appeared to support the shift toward operating more coherently as a virtual umbrella organization was the effort that so many team members made to develop and strengthen their long-distance connections, particularly in the ways that unified the project team through shared vision and broad inclusion. This willingness to help the team succeed may be particular to the LEAD project, but it may be relevant for other projects.

This study does have a limitation of relying on only one case and a small survey sample to produce our observations and generalizations. Moreover, our cross-sectional survey does not offer us the benefit of benchmarking the team's progress over time. We compensated for this to some extent with the intensive interaction we had with the project team over the past year. In the future, we would want to interview critical stakeholders, such as NSF, to see how these findings might hold across multiple similar projects. Given that several other CI projects are being studied by social scientists, we see great potential for comparing and contrasting rich data. In the meantime, we highlight the contributions of this study and offer several implications for practice and future research.

The circumstances of the LEAD project spotlight the several concerns that may be endemic to CI projects, which are of a size and configuration that remains poorly understood [14]. Foremost, we have revealed how integrating a multidisciplinary and geographically dispersed CI development team requires patience, respect, and experience, combined with a lot of extra effort, to simulate and enforce the structure of a coherent, unified umbrella organization. One way to support coherence might be through the use of collaboration technologies; however, such technologies have inherent strengths and weaknesses and often cannot substitute for each other. Instead, collaborators need to identify the combination of technological support that is right for the project. One particular vulnerability in cutting-edge CI projects is decision making about standards and priorities. Such decisions require a firm hand and special care to make sure that everyone agrees on what has been decided, and documentation is one way to clarify decisions across the team. Our results suggest that project leaders need to think deeply about the structures and resources necessary to simulate the strength of a virtual umbrella organization. Further research might reveal what methods are better at accomplishing such a goal among dispersed academic institutions.

Given the growing presence of CI initiatives, many more projects will face similar concerns as they attempt to assemble and effectively manage their teams. We suggest that people who enter into such projects must be aware that multidisciplinary, dispersed teams are not simply managed with the right tools and policies, rather the participants must be willing to make the effort to build, maintain, and learn from the relationships they will form with their collocated and far-away colleagues. Some face-to-face meeting opportunities are essential. CI projects are therefore more expensive in terms of the time needed to accomplish these tasks and the costs of supporting extra face-to-face time. The ideal situation could be a strategic mix of face-to-face meetings and distance technologies. As one PI explained, "When we do get together, we do have a very fixed set of issues you have to deal with… And then you can get something solved, and then you can use electronic mediation afterwards to work out the final details. You develop the final plan together face-to-face, and then… you have a continuation from that meeting."

However, a project still needs careful supervision to make sure decisions are clear and goals are pursued. One avenue of research would be to consider what kind of leadership is necessary for success in CI projects. The LEAD project is fortunate to have a dynamic leader who is respected in the meteorology community, by computer scientists, and for scientific research more generally. Moreover, the broader leadership and camaraderie of the PIs has set a fine example for the rest of the team, which has made the effort to work harmoniously. How have other projects found the right balance of technical and domain expertise, and what happens to morale when the leadership has a bad fit? Reviewing other current and past CI projects

may identify some answers.

To summarize, LEAD is an ambitious project that requires an exceptionally broad range of expertise. Similar multidisciplinary collaborations formed to research and develop new technologies will likely face the same issues. With enough willingness and effort, however, teams may achieve the coherence necessary for success.

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8. References

[1] B. J. Alge, C. Wiethoff and H. J. Klein, "When Does the Medium Matter? Knowledge-Building Experiences and Opportunities in Decision-Making Teams," *Organizational Behavior & Human Decision Processes, 91,* 2003, pp. 26-37.

[2] B.E. Ashforth and F. Mael, "Social Identity Theory and the Organization," *Academy of Management Review*, *14*, 1, 1989, pp. 20-39.

[3] D.E. Atkins, et al., "Revolutionizing Science and Engineering through Cyberinfrastructure: Report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure," Arlington, VA, National Science Foundation, 2003, http://www.nsf.gov/cise/sci/reports/atkins .pdf.

[4] R.E. Boyatzis, *Transforming Qualitative Information*, Thousand Oaks, CA, Sage, 1998.

[5] J.N. Cummings and S. Kiesler, "Collaborative Research Across Disciplinary and Organizational Boundaries," *Social Studies of Science*, *35*, 5, October 2005, pp. 703-722.

[6] T.A. Finholt, "Collaboratories as a New Form of Scientific Organization," *Economics of Innovation and New Technology*, *12*, 1, 2003, pp. 5-25.

[7] T.A. Finholt and J.P. Birnholtz, "If we build it, will they come? The cultural challenges of cyberinfrastructure development," In W.S. Bainbridge & M.C. Roco (Eds.) *Managing nano-bio-info-cogno innovations: Converging technologies in society*, Dordrecht, The Netherlands, Springer, 2006, pp. 89-102.

[8] R.E. Grinter, J.D. Herbsleb and D.E. Perry, "The Geography of Coordination: Dealing with Distance in R&D Work," *Proceedings of International ACM SIGGROUP Conference on Supporting Group Work (GROUP)*, Phoenix, AZ, ACM Press, 1999, pp. 306-315.

[9] C. Heath and N. Staudenmayer, "Coordination Neglect: How Lay Theories of Organizing Complicate Coordination in Organizations," In B.M. Staw and R.I. Sutton (Eds.), *Research in Organizational Behaviour*, Oxford, UK, Elsevier Science, 2000, pp. 153-191.

[10] T. Hey and A.E. Trefethen, "The UK e-Science Core Programme and the Grid," *Future Generation Computing Systems*, *18*, 2002, p. 1017.

[11] K. A. Jehn and P. P. Shah, "Interpersonal Relationships and Task Performance: An Examination of Mediating Processes in Friendship and Acquaintance Groups," *Journal of Personality and Social Psychology, 72,* 1997, pp. 775-790.

[12] T. Kuhn and M.S. Poole, "Do Conflict Management Styles Affect Group Decision Making? Evidence from a Longitudinal Field Study," *Human Communication Research, 26,* 2000, pp. 558-590.

[13] LEAD Year-2 Annual Report and Year-3 Program Plan, 1 July 2005, http://lead.ou.edu/pub_2005.htm.

[14] G. Mark and S. Abrams, "Differential Interactions and Attribution in Collocated and Distributed Large-scale Collaboration," *Proceedings of HICSS*, *38*, IEEE, 2005.

[15] M.L. Maznevski and K.M. Chudoba, "Bridging Space over Time: Global Virtual Team Dynamics and Effectiveness," *Organization Science, 11,* 2000, pp. 473-492.

[16] E.F. McDonough, "Investigation of Factors Contributing to the Success of Cross-functional Teams," *Journal of Product Innovation Management*, *17*, 2000, pp. 221-235.

[17] G.M. Olson and J.S. Olson, "Distance Matters," *Human-Computer Interaction*, *15*, 2000, pp. 139-178.

[18] J.S. Olson, G.M. Olson, and D.K. Meader, "What Mix of Video and Audio Is Useful for Small Groups Doing Remote Real-Time Design Work?" *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM Press, 1995, pp. 362-368.

[19] J.S. Olson and S. Teasley, "Groupware in the Wild: Lessons Learned from a Year of Virtual Collocation," *Proceedings of CSCW*, ACM Press, 1996, pp. 419-427.

[20] S.E. Poltrock and J. Grudin, "Videoconferencing: Recent Experiments and Reassessment," Proceedings of HICSS, 38, IEEE, 2005.

[21] J.T. Polzer, C.B. Crisp, S.L. Jarvenpaa, and J.W. Kim, "Extending the Faultline Model to Geographically Dispersed Teams: How Colocated Subgroups Can Impair Group Functioning," *Academy of Management Journal, 49,* 2006, pp. 679-692.

[22] E. Rocco, T.A. Finholt, E.C. Hofer, and J.D. Herbsleb, "Designing As If Trust Mattered," CREW Technical Report, University of Michigan, Ann Arbor, MI, 2000.

[23] J.S. Rubinstein, D.E., Meyer and J.E. Evans, "Executive Control of Cognitive Processes in Task Switching," *Journal of Experimental Psychology: Human Perception and Performance, 27,* 4, 2001, pp. 763-797.