

Chapter VII

Challenges for Research and Practice in Distributed, Interdisciplinary Collaboration

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Abstract

As private sector and government research increasingly depends on the use of distributed, interdisciplinary and collaborative teams, particularly in scientific endeavors, we are faced also with an increased need to understand how to work in and study such teams. While much attention has been paid to issues of knowledge transfer, the impact of many other consequences of distribution—disparate disciplines, institutions, career paths, time zones

and technologies—have been understudied and underestimated. In this chapter, we describe how distributed, interdisciplinary work puts pressure on existing disciplinary, institutional and personal practices—many of which are second nature to team members, and thus easily overlooked. Reflecting on our own and others’ studies of such teams, and our group’s experiences as a distributed, interdisciplinary and collaborative unit, we describe some key challenges facing such teams, including issues relating to working and learning together as experts, defining and crossing boundaries, managing external relations and working with and through technologies.

Introduction

Recent trends in work and research have encouraged businesses and research institutions to integrate knowledge from widely disparate fields, to increase the use of computing capabilities and to form inter-organizational connections; in consequence, increasing the dependence on distributed, interdisciplinary and collaborative teams. Private sector investment in alliances has been paralleled by large-scale government investment in research infrastructures, programs and centers, and both have called on researchers to work across knowledge domains, organizational norms and physical and conceptual boundaries. While earlier research has suggested that the main problem for such work is making tacit knowledge explicit for transfer to others, we suggest that contemporary teams face a more complex set of issues as they engage in joint knowledge construction. Contemporary team members find that they cannot simply transfer their previous collaborative skills to a widely distributed, interdisciplinary arena, but must continually renegotiate a wide range of research and work practices thought to be already established. As Knorr-Cetina (1999) has remarked about scientific teams, current research initiatives often bring together quite disparate disciplines, locations and technologies, often leaving a single researcher of such teams woefully at a disadvantage to understand a team’s work. Studying contemporary teams requires a more comprehensive examination than is commonly employed, encompassing interdisciplinary processes, group interaction, institutional practices, career interests and uses of information and communication technology. Moreover, contemporary views that consider technology as providing the solution to the “problem” of collaboration—e.g., through faster connection, seamless integration of geographically distributed people and projects and new information and communication technology infrastructures—fail to acknowledge the negotiation of practices and the coevolution of practices and

technology that are involved. Collaborations involve dealing with existing embedded practices, as well as emergent ones that take time and effort to evolve.

In this chapter, we draw on previous work in these areas, and, equally important, on the collected experiences of our group—the Distributed Knowledge Research Collaborative (DKRC)—as we observed, studied and participated in distributed, interdisciplinary and collaborative work, to articulate a series of key challenges we find facing contemporary teams. DKRC began in 1997 with the seven future co-PIs composing a grant application to the NSF Knowledge and Distributed Intelligence (KDI) initiative. At the time, all members were co-located at the University of Illinois at Urbana-Champaign: One worked for NCSA (National Center for Supercomputing Applications), and two each in the faculties of Education, Management and Library and Information Science. Members were and remain interested in the impact of technology and new organizational structures on contemporary scientific and work practice. By the time we received funding in 1999, we were located at four universities, and later at five locations across the United States. Starting in 1999, the team has included a number of graduate students who are also distributed across disciplines; an average of about one student per co-PI per year, but with more than seven over the years of the grant.

We have been exploring the ways in which distributed, interdisciplinary and collaborative teams accomplish their work. The teams we have studied include science teams in the fields of biology, cosmology, environmental hydrology, and nanotechnology, as well as social science teams. These teams were chosen as examples of successful endeavors, approved and funded by significant granting agencies, and supported by university and research center infrastructures. We began by interviewing key informants in each team to hear about group organization, administrative procedures and research concerns. We then studied their group collaborative practices using ethnographic, bibliometric, qualitative, and social network methods, and also examined group technologies (e.g., a modeling and visualization tool, digital library and database), and artifacts (e.g., documents, web sites, reports, and research articles; Porac, Wade, Fischer, Brown, Kanfer & Bowker, forthcoming). This work has been backed with considerable discussion and inquiry into what it means to be collaborative in today's scientific world, and how the literature has dealt with the notions of collaboration, knowledge co-construction and the use of technology (see Kanfer, Haythornthwaite, Bowker, Bruce, Burbules, Porac & Wade, 2000). Throughout our work, we have been deliberately conscious of our own activities as a distributed interdisciplinary team, and how these compare and contrast with those of other groups.

We draw on the following sources in identifying the key challenges outlined in this chapter: the experiences of groups we have studied; our own experiences

studying them and operating as a distributed, interdisciplinary team; and the literature on interdisciplinarity, learning and group processes. There are many challenges to any kind of team endeavor, but we concentrate here on characteristics and considerations which have special importance to distributed, interdisciplinary and collaborative work groups. We collect the challenges together under these headings:

- Bridging Practices
- Seeing and Crossing Boundaries
- Managing External Relations
- Working With and Through Technologies

We do not consider the discussion in this chapter to be exhaustive, but as identifying key factors. These are presented to inform and prepare those embarking on distributed, interdisciplinary work and as a basis for future investigations.

Bridging Practices

Collaborative, interdisciplinary teams are typically composed of experts, or individuals who are highly knowledgeable and proficient in their own work and its practices. Through education, work experience and years of research, teaching, managing and/or mentoring, expert team members have become entrenched to differing degrees within a disciplinary framework. To an expert, disciplinary, institutional and personal research practices are deeply ingrained and often invisible. The challenges experts face in communicating, learning from each other and collaborating are markedly different from that of novices. Where transfer is often the main metaphor for novices, the watchwords for expert interactions are joint problem-solving, shared cognition and co-construction of meaning.

As other writers have explained, experts learn and make sense of problems differently from novices. In contrast to novices, experts approach problems with attention to the principles that can be drawn on to solve them rather than to surface attributes. They are more adept at perceiving patterns, and at understanding the conditions under which the knowledge will apply. They are skilled at metacognition, “the ability to monitor one’s own current level of understanding and decide when it is not adequate” (Bransford, Brown & Cocking, 1999, p. 47).

In principle (although not always in practice), experts maintain an openness about their state of knowledge and need to learn, and maintain flexibility in their goals (Bransford, et al., 1999; Scardamalia & Bereiter, 1996). Yet expertise is firmly rooted in disciplinary and institutional homes. Tacit intradisciplinary understandings about how to examine a problem, what knowledge to bring to bear and how to go about work can get in the way of seamless interdisciplinary collaboration.

Perhaps the most overlooked aspect of interdisciplinary teams is how the embedded *practices* of each discipline form as important a bond as any other part of its domain knowledge. Disciplinary expertise encompasses more than just the facts about the field; it includes knowing what is important for the field, where new problems are emerging, what problems are considered worth tackling and how to formulate and publish ideas and accomplishments to meet grant and promotion requirements. More specifically, it includes field-specific standards in what constitutes data, how they should be collected and shared, what analysis techniques are accepted and when and where data and results are published (see also Fienberg, Martin & Straf, 1985). Interdisciplinary teams are therefore challenged to integrate not only disciplinary knowledge, but disciplinary practices, including coming to joint understandings about data collection, data sharing, methods and analysis techniques and publishing practices. Such integration can be slow and difficult, in part because we are so entrenched in our ways of approaching problems, and partly because we enter such collaborations without considering integration work to be part of the effort that is going to be needed (Bowker, 2000; Watson-Verran & Turnbull, 1995).

To integrate knowledge across different fields, experts must spend time and effort sharing knowledge and creating common understandings. Active discussion and engagement are essential strategies for achieving this (Clark, 1996; Cook & Brown, 1999; Engestrom, 1999; Klein, 1990), yet one of the major challenges faced is providing the operative infrastructure that allows experts sufficient time to bring their expertise to bear on a problem. Studies summarized by Bransford, et al. (1999) show that experts' apparent fluent retrieval of the appropriate knowledge to bring to bear on a problem does not mean it takes them less time than novices to solve problems. Rather, we are faced with the "mythical man-month" problem (Brooks, 1975)—communication time increases exponentially with the addition of more experts. Duncker-Gassen (1998) demonstrates how this occurs in practice: The experts need to develop a common language in which just enough and not too much of their internal expertise is communicated at team meetings. It is not surprising, then, that at a recent NSF workshop for principal investigators on interdisciplinary projects, a common lament was that everything took more time than expected (NSF KDI workshop, April, 2002; for a report see Cummings & Kielser, 2004).

In addition, changes in disciplinary practices also continue to meet barriers created by institutional practices. In interviews with research team members, and in comments in many academic venues, university promotion and tenure (P&T) committees are repeatedly named as arbiters of academic practice, and thus weigh heavily on the minds of interdisciplinary researchers, particularly team leaders and mentors who have the interests of their doctoral students and untenured faculty in mind. P&T committees have the power to make or break an academic career, and thus what they accept in terms of academic practice significantly shapes and constrains research activity. Several issues—including standards about co-authorship, publication venues and legitimate research methods or subject areas—may limit on what and with whom group members will work, as well as where and how work will be expressed and distributed. Recent attention has been given to the acceptability of electronic publications. Kling, McKim and King (2003) report that at a workshop on electronic journals at an information systems conference, many participants, and in particular more junior scholars, reported they were afraid to publish in new electronic scholarly communication forums because of a concern that “their Promotion and Tenure (P&T) committees would not count these publications or would disapprove of them in promotion decisions” (p. 67). This problem is even greater for humanities scholars (and some social scientists) who engage in work with new technologies. Their challenge can be even greater because collaborative activity is not yet regarded as acceptable to many promotion committees. Those combining new computer developments with collaborative and interdisciplinary activity then face a further hurdle as they try to find outlets for publication and recognition of their work (Greenblatt, 2002).

Similarly entrenched notions of how grant funding is given, for what, and for how long, may hamper the efforts of those working on and examining infrastructure development. Kling, et al. (2003) describe how the use of FlyBase, a database about the *Drosophila* (fruit fly) genome, ran up against this problem.

FlyBase is not funded as an NIH [National Institute of Health] line item—rather, the coalition must apply for new grants every 3-5 years. NIH research grants are generally not given for maintenance and operations, but rather for new developments. Therefore, the FlyBase coalition must continually propose the development of new features to receive funding for continued operation. (Kling, et al., 2003, p. 62)

A social science group we studied faced the same kind of problem at the end of its first grant funding. Having developed an environment for evaluating, maintaining and disseminating educational materials, they reached the end of their

grant and were left searching for ongoing support for maintenance and further development.

Thus, we see how conceptions and preconceptions about what constitutes disciplinary practice can limit interdisciplinary work, and how existing social, technical and institutional frameworks may conflict with the emergent nature of interdisciplinary efforts, as well as emergent, continuing needs.

Practices within Teams

Practices within teams are also often overlooked in measuring the complexity of interdisciplinary collaboration. While all teams face difficulties in pooling and sharing knowledge and making the most of member contributions, interdisciplinary teams face particular challenges around their lack of redundancy in disciplinary coverage and their lack of a shared base of domain and procedural knowledge. Interdisciplinary, collaborative teams have *knowledge interdependencies* that may be overlooked or oversimplified if a mono-disciplinary model of work is assumed. These interdependencies manifest themselves in several ways. As a group, interdisciplinary teams depend on members to represent their disciplines and to bring that knowledge to the team's work. Consequently, members representing that discipline must take on the responsibility to be present and contribute continually to the overall endeavor. As a corollary, those from other disciplines must be open to hearing and incorporating such knowledge. To integrate and synthesize knowledge, the group must be ready to engage together in contributing knowledge and learning from others.

Learning as a group may be mutual as members gain new knowledge together—what might be described as *co-learning* (e.g., through joint discussion of papers read in common, bringing in experts to consult with the team and attending conferences together). Individuals may also learn on behalf of the group, e.g., by expanding their knowledge of another's area, or even engaging in *altruistic learning*, as individuals learn for the sake of the group. For example, individuals might take classes or visit other laboratories to bring expertise in a software program or research technique into the group. Strategies to promote such learning may include reading about the content or methods of another's discipline, doing background research to gain knowledge in new common areas or learning with the intent of training others in the group (for more on learning in groups, see Argote, Gruenfeld & Naquin, 2001).

Learning also entails getting to know other members of the team, and what they know. Members form *transactive memory* (i.e., memory about “who knows what”; Moreland, 1999; Wegner, 1987) about each other's knowledge, expertise, methodologies and approaches, working styles, available time and commit-

ment. They acquire knowledge about each other's disciplines, come to understand what work may forward an individual's career and how these constraints play out in an individual's needs and urgencies (e.g., to finish a dissertation in a year; to publish for tenure packages). Team members also learn who does what tasks and who has what responsibilities (Brandon & Hollingshead, 1999). Once "directories" of who knows what are in place (whether in the heads of team members, or held externally in knowledge management systems), team members can reduce their own information load and responsibility by forwarding information and/or questions to appropriate experts (Monge & Contractor, 2003; Palazzolo, 2003; Wegner, Giuliano & Hertel, 1985). Such learning also builds common ground as group members create a collective or *community memory* that defines them (Orr, 1996; Chayko, 2002; see also the section on "Seeing and Crossing Boundaries").

However, these learning processes may also involve shedding existing biases and predispositions regarding what others do in their domain. We may begin with projected notions of what others do and think as computer scientists, biologists, sociologists, psychologists, etc. Biases include stereotypes about personalities, data collection practices, attitudes toward study participants, analysis skills and technology skills and interests. Yet, these stereotypes rarely hold, and someone representing one discipline may have spent a long time working in another and thus be expert in several fields and approaches. Indeed, our own group, which we present as a whole as composed of social scientists, includes PIs with academic degrees in computer science, education, history, information science, management, philosophy and psychology; home departments of communications, education, library and information science, and management; work experience both in and outside academia; and research endeavors from sociology of science to the development of educational technology.

Preconceptions about people may also apply to projected notions of their willingness to learn. Novices may be expected to learn widely, yet degree requirements for graduate students may focus them more narrowly on their own discipline. Senior experts, by contrast, may be thought of as narrowly defined, yet by taking on the interdisciplinary endeavor may be learning more widely. Sharon Traweek's groundbreaking work on the high-energy physics community is key here (Traweek, 1992): the senior physicist tends to believe more in (and has more to gain from) active collaboration than the junior researcher who has yet to stake his own claim to a piece of the field (cf. Star & Ruhleder, 1996). The expert who acts as an "accomplished novice" may come from any field, yet junior participants such as students may never before have experienced cooperative and collaborative practices with senior experts, and thus have neither expectations or practical experience with such practices. Because of their invisible nature, we may also forget to include training in interdisciplinarity and collaborative methods when we introduce new people into a team.

Preconceptions also include assumptions of who will work with whom, because of their age, discipline, home institution, etc. Often graduate students are expected to talk and work with each other, yet this can be an added burden when they are only beginning to gain expert grounding in their own discipline. To talk across disciplines requires a solid understanding of typical practices such as collecting and analyzing data and making appropriate claims, as well as the ability to think abstractly and metacognitively about how combining widely disparate disciplinary efforts may challenge and redefine one's home practices. Many PIs at the NSF KDI workshop commented on how their students had not yet acquired sufficient disciplinary skills when they were plunged into interdisciplinary work. Thus, PIs need to judge when their graduate students are as ready for interdisciplinary work as they are for disciplinary work.

When assumptions are made about others' work, there may be preconceptions about *how collaboration will proceed*: for example, what kind of information or data will be made available to all members of the group, when this will occur, what pre-work enables that sharing and whether data can be shared across scales, methods, human subjects permissions, etc. We also have assumptions about *how work will progress*, for example, from setting goals to designing studies, collecting data and producing papers. If team members tacitly anticipate a certain set sequence of research design, data collection, analysis and publication, they may ignore the more complex logistics necessary for collaborative work, such as the pooling of data and resources (equipment, bibliographic citations, etc.), as well as the appropriate synchronization of different tasks. Even if team members share expectations about a project's goals and progression, how do these match the expectations of the external organizations that house and/or fund them? How can they convey new, evolving, interdisciplinary practices and outcomes to funding agencies, participant organizations, advisory boards, universities and departments?

In our own work we have found several instances where expectations were out of synch with what was possible, or what others thought. In data collection, we found that research participants prejudged their role in our research, e.g., declining interviews because they "didn't know anything about interdisciplinary activity," when we wanted to hear about what they did. Similarly, we found that participants prejudged our aims as "evaluative" and thus feared an impact on their future grants. We find we are not alone in being judged this way: Suchman, Blomberg, Orr and Trigg (1999) report how they took "great pains" to explain the point of their observations and recordings of work processes in an organizational context, where "it is difficult for people who have grown up in the shadow of scientific management to imagine what interest researchers could have in their work other than to evaluate it in terms of workers' competency and efficiency" (p. 398).

Likewise, in managing our own collaboration, the co-PIs spent over a year meeting regularly in preparing the grant application and developing common consensus on research approaches. Yet, once we got the grant, graduate students were brought on and expected to “just know” about the collaborative approach the PIs had spent so much time showing each other. We also failed to recognize assumptions about different methods we were using, including how well results from different methods could be timed to feed into other parts of the overall work (e.g., ethnographic results into social network studies). As we tried to put work together, we found our different approaches came with different and sometimes conflicting needs. Members have had to negotiate expectations for defined versus open-ended study populations, hypotheses over more open-ended research questions and results verified by statistical tests versus philosophical reasoning (e.g., statistical testing of the impact of membership on collaborative grants to numbers of publications, versus open interviews coded based on principles of grounded theory vs. philosophical analyses of the nature of collaboration). Each of these has represented challenges to our own work that are also likely to be faced by others.

Seeing and Crossing Boundaries

A further challenge to interdisciplinary endeavors is the time and commitment members give to a particular project. Experts have their operations in other fields, and spend only limited time in the interdisciplinary endeavor. They have different notions of their involvement than do outside observers.

The challenge of boundaries became apparent to us when we tried to define who belonged to the groups we wanted to study. Despite the existence of web sites listing contacts, grant funding agency documents with PI names and lists of employees in organizations, this was not an easy task. We found ourselves asking: What constitutes a person, a collective, an institution? There are answers which everyone knows intuitively, but we found the entities ever more ill-defined as we tracked them acting in our teams. Within the distributed projects we studied, every collective designation proved problematic. Who were the members of the research team? It certainly was not the list of people to whom the grants were awarded—members dropped out and came on board over time—so that the organizations we were studying (NCSA and the home institutions of the grantees) often had different accounts of membership. PIs receiving only small percentages of funding from a particular grant would remind us of where this fit in the larger arena of their research. We had to ask whether 5% funding led a PI to consider him or herself committed to the project (and if so to what extent), and whether this level of involvement meant they counted as a “person” or “unit”

in terms of group membership. Is the definition of the collective “group” based on those with some minimal time or funding involvement, or does it consist of the names on a web site? Is an organization involved if only one member of their staff, now departed, used to work on the project?

A similar problem came when considering how team members represented a particular discipline. Does an individual represent computer science (CS) only if they have a degree in CS? What if they are working on a CS degree but don't yet have one? What if they had worked in computing but had no CS degree? What if their degree is in CS, but they work in a different department—which discipline would we say they represented? What if they published in CS journals, or about CS in non-CS journals—does that make their discipline CS? The answer probably lies somewhere between “all of the above” and “none of the above,” that is, somewhere in the interdiscipline.

Intra-Team Boundaries

How individuals set boundaries for themselves, partitioning and allocating time to projects can significantly impact scheduling and coordination. Scientists involved in several grants may apportion time and commitment based on which team demands the most time, which team is just in the beginning stages of work (or other critical stages), which team members are most local and therefore most visible for reminders about work or which working arrangement or topic is more prestigious or popular. Within the project, teams negotiate the boundaries of work, including roles, responsibilities, project scope, and intended outcomes. They set *temporal* boundaries, such as when the project will end (or, more instrumentally, when the funding will run out), and *trajectories* for the work, essentially mapping out future boundaries against which progress will be measured.

Interdisciplinary teams learn to partition and allocate time, money, and resources, as well as access to equipment, software, data, reports, and people. For example, when studying the same group from multiple perspectives, we needed to manage our own access to respondents. We considered how to space requests over time, and limit access to a team to only one set of researchers at a time, much as others might book time on equipment or for the use of computing resources. Researchers thus may be seen to mark *territory*, for example, deciding who studies who and when, determining hand-over points and coordination schedules. As researchers, we became aware of distinctions between our disciplines based on differences in methods and approaches, and attitudes to the relationship between the researcher and the participant (e.g., the invisible observer or arms-length researcher versus the involved, participant observer).

Individual Attitudes to Boundaries

Group members also consider the boundaries to their own identification: What discipline do they feel they speak for when working on an interdisciplinary team? How do they explain their work to their home discipline (however defined)? How do they describe their work when it is presented for tenure and promotion? Many individuals on the teams we have studied have been acutely aware of this problem of crossing boundaries.

Team members may also differ in their need to define boundaries for their work, and whether their own perspective sets boundaries (or eschews them). For example, some researchers may not be comfortable unless the boundaries of the study population are set—and hence seek definition of such boundaries by creating operational definitions of inclusion and exclusion (e.g., being on the payroll, listed on a website, belonging to a department; or bounded by geography, politics or topology). Others may accept a more emergent, even amorphous boundary, and hence see emergent definitions of involvement (e.g., by using “snowball” techniques that begin with a set of people and ask them who to talk to next; or by letting boundaries emerge from observation). Comfort with this definition, and even the need for a definition, affects how team members view the legitimacy of the work.

Goals as Boundaries

Goals act as boundaries, orienting, but also constraining, activities. Our research suggests that interdisciplinary activity particularly needs to accommodate change and adjust goals. Indeed, we argue that the goals of interdisciplinary groups *need* to evolve so they do not become barriers instead of boundaries.

In defining boundaries, creating schedules, marking territory and establishing trajectories early in an interdisciplinary project, groups can close discussion too early; discussion based on a non-confrontational, “illusion of friendship” (Klein, 1990) may lead to quick agreement, missing the opportunity to learn from each other, jointly “formulating and debating a problem” (Engstrom, 1999, p. 380), setting a joint agenda and generating new knowledge (Cook & Brown, 1999). Not only is knowledge about the interdisciplinary endeavor at an early stage, and should be kept open for the generation of new knowledge (Cook & Brown, 1999; Haythornthwaite, Lunsford, Kazmer, Robins & Nazarova, 2003), so should the tasks and outcomes be open for continuous negotiation. While all groups have work to achieve—and as such need to come together around a common goal, and to create and determine schedules and processes—interdisciplinary groups, especially those forging new interdisciplinary relations, face the particular

challenge that outcomes of their work may not be apparent when they begin working together. Too many approaches to interdisciplinary work start with the premise of a predetermined, fixed end to be achieved. The organization of work that ensues can inhibit collaborative interchange. For example, in a collaboratory for structural biology studied by one of our members, well-defined roles and schedules existed for gathering information on what the user community required (first stage of project), coding that requirement into collaboratory tools (second stage) and then evaluating the overall result (final stage). While these well-defined roles produced a collaboration of sorts, the coordinated activity reduced two-way collaboration, for example, participants entering late in the schedule were not working together with those whose roles entailed earlier work. What results is not collaboration, but work characterized by coordination, as pieces are handed over as completed, thus missing the potential benefits of fully collaborative interaction.

Interdisciplinary work may be particularly difficult precisely because *goals emerge from the interaction, not prior to it*. We believe that interdisciplinary, collaborative work requires *continuous negotiation and co-construction of outcomes*, which further entails continuously engaging individuals around the definition of an emergent and mutually agreeable result from the work (see also Haythornthwaite, et al., 2003).

Defining parameters early may also lead to misconceptions about what other team members know or will do. Our knowledge about group members is at a formative stage when we begin to work together, as is our knowledge of what tasks others are responsible for and what they know (Brandon & Hollingshead, 1999; Wegner, 1987). As an outsider looking in on knowledge processes, we may fail to acknowledge the side-tasks and invisible work (Star & Strauss, 1999) that are so important to group functioning. Just as many early management literatures focused on “process losses” and failed to give weight to the social relations that keep members committed to the group (McGrath, 1984), so, too, a focus on interdisciplinary knowledge work alone fails to recognize other corollary knowledge exchanges. Results from the scientific teams we studied (Haythornthwaite & Steinley, 2002; Haythornthwaite, 2005) suggests that a number of apparently extraneous kinds of knowledge represent important exchanges among team members, including advice on how to work with funding agencies, knowledge of who outside the team can provide personal references or knowledge about future jobs for graduate students. From our own experiences, we know the importance of gaining knowledge about how to communicate via video and audio-conferencing. Seemingly inconsequential issues, such as learning how to accommodate temporal delays in videoconferencing and how to include invisible phone participants, reflected very important gains in our ability to accomplish work and communication at a distance. (These issues are addressed further in the “Working With and Through Technologies” following section.)

Managing External Relations

Managing external relations may be considered a corollary to the discussion of boundaries given above, but in this section, attention is given to what is outside rather than inside the boundary. It is important for teams to recognize and manage both individual and group relationships with these external entities. As Ancona and Caldwell (1990) note:

To be successful, new product teams must obtain information, resources, and support from others, both inside and outside of the organization, use that information to create a viable product, and finally transfer the technology and enthusiasm for the product to those who will bring it to market. . . . This makes the new product team highly dependent upon others, and suggests that an important way of understanding the performance of these teams lies in examining how they manage relationships with other groups. (Ancona & Caldwell, 1990, p. 120)

New interdisciplinary teams, like new product teams, have ideas, projects and careers to sell to granting agencies, home departments and universities.

Teams, particularly grant-funded teams operating in departments in research institutions, manage a number of layers of external relations, some of which have been mentioned above: home departments and colleges, university (or other institution) administration, review boards (e.g., Institutional Review Boards (IRBs) that sanction the ethics of the research), and granting agencies. Teams and team members often need to manage an image of themselves that is then often used again to promote the external agencies. Thus, teams may liaise with the public through brochures, pamphlets, web sites and interviews. Teams are also seen as representatives of such agencies, and may be required to identify their association under some circumstances, as well as, paradoxically, disclaiming the agencies' involvement with the results that are presented (e.g., through the addition of lines such as "The findings presented in this report do not necessarily reflect the views of the <fill in the blank> agency").

Team members also act as representatives of interdisciplinary work in their home disciplines. Thus, legitimate responsibilities for such work includes taking information, knowledge, practices and methods *back* to home disciplines where they may be used by others (Kanfer, et al., 2000). This may pave the way for the next generation of interdisciplinarians in a form of legitimate peripheral participation (Lave & Wenger, 1991), as well as legitimizing the interdisciplinary endeavor, and possibly fostering new practices in the home disciplines.

Working with and through Technologies

As contemporary groups work and forge new synergies, they typically do this with attention to the adoption, integration and creation of new computing technologies. Both funding initiatives and peer pressure in many settings encourage teams to adopt new technologies to support distributed knowledge processes and creative work. We separate out our discussion of them here because they add another, often unrecognized, cognitive and logistic load on contemporary teams, as new technologies require the development of new practices and the reinvention of old ones.

Bridging Practices with Technology

To bridge differences in disciplinary practice, teams often define social and technical infrastructures to support their joint work. Many contemporary teams include as part of their mandate the creation of new technologies relating to their research endeavor, such as data repositories, software, analysis techniques, digital libraries and collaboratories for shared data collection and analysis. This work entails both defining protocols, data units, database structures, computer interfaces, storage and retrieval techniques, etc., as well as encouraging joint use of these technologies. In the same manner as for learning, members may need to engage in altruistic use of technologies, seeding shared databases to establish a critical mass of data or communication that makes the effort worthwhile for others (Markus, 1990; Connolly & Thorn, 1990).

However, it is at the definitional interfaces that interdisciplinary teams in particular meet many challenges. Disciplinary standards on data units, naming conventions and analysis techniques must be generalized to cover many disciplines. Those who study processes that unfold over millennia try to match up with data from those who study yearly phenomena. Those who work with quantitative data and approaches try to match up with qualitative data and approaches. Moreover, long-held definitions about what a concept means or a thing “is” have established infrastructures that affect what kinds of questions are asked by certain disciplines (see Bowker & Star, 1999). Likewise, evolving definitions for new entities, such as “collaboratories,” affect what counts as the object of study by different disciplines (see Lunsford & Bruce, 2003).

To illustrate the complexity inherent in the meaning of a thing, consider bringing experts together to work on a simple thing like soil (Gray, 1980; Bowker, 2000). Different sets of researchers will have very different intuitive definitions of what soil is. An agriculturalist views soil as something crops grow in; ecologists see

soil as including hard rock (to which lichens cling), and as part of the earth's surface subject to weathering influences. Such disciplinary views suggest specific ways of looking at soil, and each suggests different kinds of questions to ask. What constitutes the "universe" of soil differs by classification scheme. For example, soil classification schemes used for North America and Europe include national variations found in those countries. However, since these countries lack a tropical climate, soils of the tropics do not get detailed coverage in these classifications. Thus, geographic and interdisciplinary differences can predispose researchers to a particular view of a supposedly common object. In interdisciplinary work, definitions need to be reopened and compared across fields, adding to the overhead of such work the time it takes to complete projects, and the uncertainty regarding what the project is about.

Importantly, while systems development is rapid, change in practice is slower and more complex. Practice is bound up with traditions within fields, entrained with funding cycles and the need to show results. You cannot, as the Flora of North America (<http://www.fna.org/FNA/>) project discovered, easily convince botanists to move from traditional glossy plates and printed text to electronic publication of only partially-vetted results. Change in culture is slow even though this kind of advance is doubly useful as it speeds up work within the botanical community, and opens the borders of that community for researchers in cognate disciplines to tap into ongoing work more readily. Similarly, the Long Term Ecological Research (LTER) network (<http://lternet.edu/>) has found difficulty trying to convince researchers to produce truly interoperable databases: Everyone agrees it would be valuable; however, getting scientists to think outside their current project (and funding cycle) is extremely difficult.

Comparable difficulties are found in spanning disciplines. For example, the new field of systems biology, which melds computer science, engineering and biology, entails a change from analyzing "one gene or protein at a time" to examining "a living thing as a whole":

Doing systems biology requires a huge change in the research culture. . . In traditional molecular biology, each scientist works on his own gene, but the systems approach requires determining the effect of every gene on every other. You have to give up this 'my gene, your gene' stuff. (Eric Davidson, quoted in Begley, 2003, B1).

A general rule of development to date has been that domain scientists have been left to deal with the cultural change on their own, with input from frustrated systems developers who wonder why their programs are not being used (Star & Ruhleder, 1996).

Similarly, different fields have different ideas about when data should be made public, for example, when collected, after publication of results or not at all. There are different standards on publication venues (online or offline; proceedings, journal article and/or book), and authorship practices (single or multiple; including or excluding research assistants). Moreover, such approaches are often so intricately tied to what it means to be a biologist, computer scientist, or psychologist that it is extremely difficult to accept another's methods as legitimate practice, *and* to have those practices accepted across fields and departments. Interdisciplinary groups must make integrative efforts to learn and communicate not only in combining what is known in a field, but also in bringing together their various approaches and forms of data collection and handling, and applying technologies that suit both individual needs and joint work. Crossing such divides, reopening definitions and even recognizing that differences exist, add to the challenges of interdisciplinary work (see also Haythornthwaite, 2004).

Bridging Distance with Technology

As developments in information and communication technologies make it possible and expected that we can work at a distance (anytime, anywhere), we find that we are paradoxically more fragmented in our communication channels at the same time as endeavoring to be more integrative in our practices. Not only must groups create new technical infrastructures to bring their different work together, they also learn "side" activities associated with accommodating distributed work practices. They must coordinate work schedules across time and geography, establish norms for interpersonal communication via new media and keep up with the ramifications of the everyday presence of information and communication technologies (such as on and offline publishing standards and the need for representing the team's research on the internet).

Finding opportunities to communicate are more difficult for teams that cross departments, institutions and geography since their activities do not have the same entrainment (McGrath, 1990) to local environments (e.g., the local coffee spot), events (e.g., faculty meetings, pub nights), schedules (e.g., semester cycles, holiday breaks) and time zones (e.g., common work hours). Although it may seem a trivial point, such lack of common time can seriously hamper scheduling joint activities. For example, in our own group, with members from the east to the west coasts of the U.S., we have had to find meeting times that do not have our west coast participants up at 6 a.m., and yet do not occur during anyone's core hours of the day when their own local meetings and classes take place. Further, operating on different semester systems means our break times do not regularly overlap, and so face-to-face meetings are shoehorned into what

overlap does exist, often meaning long delays between such meetings. Thus, we have found that we spend time learning about the schedules and daily operating routines of institutions other than our own. (See also Livia, 1999, who describes how time zone differences between herself and her research partners and participants affected doing research via the internet.)

Distributed groups may find that part of their learning to work together involves experimenting with computer-mediated communication (CMC) and work tools for distributed meeting support, as our group has. Asynchronous tools, such as e-mail, modify the way individuals communicate information and coordinate their actions—paradoxically both enhancing and constraining communication (for reviews, see Kiesler & Sproull, 1992; Wellman, Salaff, Dimitrova, Garton, Gulia & Haythornthwaite, 1996; Haythornthwaite, Wellman & Garton, 1998; Herring, 2002). For example, the reduced social cues in an e-mail message may constrain coordination efforts by failing to engender commitment to a course of action. Overload in e-mail may lead to important messages being lost in a sea of other communications; and social gatherings may be curtailed because of a perception that e-mail (or other forms of CMC) is “as good as being there.” At the same time, e-mail communications may provide an ideal way to keep everyone in the loop on activities, and provide an easy, central means of coordinating action and recording activities.

Our own experiences with communicating via a combination of conferencing media highlight some ways in which technologies modify group dynamics, and how we had to learn to adjust to them. A common setup for us for most of the project has been to have a set of people face-to-face in a conference room, a video display bringing in participants from one to four sites across the U.S. and audio-conferencing for remote participants without video capabilities. We have found that distributed group members who join meetings by videoconference, while visible and obviously present, are disadvantaged in conversations because the one to three second transmission delays are just long enough for non-delayed speakers to jump in first. Phone participants, on the other hand, are physically invisible and in danger of being forgotten as present at the meeting. The presence of others in the local meeting room (seen face-to-face) and/or on the larger-than-life video display, overshadows these invisible listeners. Over time, we have learned to pause the requisite one to three seconds for responses from video-attendees, to poll those “in” the phone for contributions, to voice a “yes” rather than nodding and to attend to more tacit signs of presence, such as an additional breathing over the phone, or sounds that indicate a new person has dialed into the conference system.

As groups look to technology to support their work processes, we add the caveat that technology (such as videoconferencing) does not provide a “solution” to the “problem” of collaboration. Instead, we see technology both emerging from and

modifying practice, leading on to the next generation of problems and solutions. This *pragmatic technologies* view (Hickman, 1992) allows us to see technologies as both antecedent and consequence of distribution, interdisciplinarity and collaboration, and groups as able to both adopt and adapt technologies to their needs (Bruce & Hogan, 1998). Similarly the *adaptive structuration* view (Descants & Poole, 1994) lets us see social processes emanating from group uses of a technology rather than some standard across-the-board definition of use. Like interdisciplinary outcomes, technology use by groups and for groups needs to be seen as developing from use, and to recognize that such changes and emergent use are important aspects of interdisciplinary, collaborative practices.

Conclusion

We have brought together here some challenges characterizing distributed, interdisciplinary, collaborative practice, encompassing learning and communicating, preconceptions and expectations, boundaries, external relations and social and technical infrastructures. Although many groups, interdisciplinary or not, collaborative or not, will face the challenges discussed here, we find that another challenge for distributed, collaborative groups is one of *quantity*: At every turn there is another aspect of group operation, interaction and endeavor that must again be worked out from scratch. Education into a single field does not prepare us for the many factors that drive and sustain successful interdisciplinary, collaborative work.

With this long list of challenges, we are concerned lest the reader feel that we have established a wall of obstacles to interdisciplinary progress. To the contrary. There are good research and structural reasons why agencies should fund and support integrative efforts. Chief among them, perhaps, is that the issues we face in managing the planet (climate warming, biodiversity preservation) and in managing complex social and political decision making (the tribulations of a globalizing world) necessarily call forth interdisciplinary responses. However, we believe the success of such endeavors will depend on recognizing the characteristics and challenges to such work, and acting to support this new kind of work. Moreover, the challenges must be recognized as both technical and social: Doing technically integrative, interdisciplinary work represents a major change in the way people work together, what problems they address and how and what products they complete as a result. Yet it remains an opportunity to be pursued.

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