Work at the Boundaries of Science

Information and the Interdisciplinary Research Process

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PREFACE

> Knowledge about knowledge has a peculiar multiplier or leverage effect on the growth of knowledge itself. The more we know about learning and the transmission of knowledge, and the more we know about the processes by which knowledge advances at the frontiers, the more efficient will be the use of resources, both in education and in research.
>
> —Kenneth Boulding, *Beyond Economics*

The value of knowledge about knowledge, as expressed in Boulding's statement above, conveys the basic premise behind this book. Understanding how knowledge is produced and communicated is key to creating better conditions for knowledge development. Information, as a constitutive element of knowledge, plays an important role in the leveraging phenomenon identified by Boulding. To improve information resources for the pursuit of knowledge, we must first learn how information works at the knowledge frontiers. The research fronts of science supply a microcosm where we can see researchers working on scientific problems. The real-world research problems that scientists address rarely arise within orderly disciplinary categories, and neither do their solutions. Thus, the information needed to solve complex research problems is distributed across disciplines and takes many different forms, physically and intellectually.

Our stores of information are diverse, scattered, immense, and unwieldy. Information may be amassed in records and documents kept by organizations or stored in libraries, archives, and information systems. Some information exists only in personal or organizational memories. Tempered by the social and cultural facets of its creation and use, not all information is visible or usable. For example, some information circulates widely while some lies dormant, and esoteric languages may make specialized information incomprehensible to those outside a discipline. Moreover, the organization of any collection of information reveals certain features while disguising others.

It seems a wonder that scientists manage to be productive and innovative amidst this complicated resource base. But, they do, and in turn their ways of working with existing information to create new knowledge tell us much about the enterprise of science and how to foster its advancement.

The empirical work that fed into this book began in 1992 when I got involved in a three-year federated research project investigating interdisciplinary scientific communication and research processes. The team members on that project were based in a number of social science fields—anthropology, communication, sociology, and my field of library and information science. United in our interest in the knowledge structures of scientific communities, we investigated a series of questions related to social and organizational aspects of communication, information use and exchange, and legitimacy and competition in interdisciplinary science. Due to our diverse backgrounds, we brought a broad perspective to the project and used a range of methods, including citation analysis, network analysis, survey questionnaires, and structured interviews. Pertinent results from that federated research, referred to as the "general survey" within the text, have been integrated into the analysis presented here. That project in its entirety formed a solid foundation for the independent research I undertook in subsequent years. As a sole investigator, I followed a similar line of questioning. My aim was to identify the critical components of the interdisciplinary research process to inform the development of advanced information systems and services for innovative problem solving and inquiry.

The applications I envisioned for this research are important, but information science is but one of a number of audiences concerned with the interdisciplinary research process. Research administrators and practicing scientists and scholars from a range of fields are interested in creating and working in environments that help researchers traverse intellectual, cultural, and organizational boundaries. Within the literature, this research fits in the growing field of knowledge studies that cuts across the social sciences and the humanities, and it contributes to the body of social and practice-based studies of science and knowledge production. It follows in the tradition of studies of science communication that have infused information science at least since Derek de Solla Price's *Science since Babylon* (1961) brought attention to the role of recorded knowledge in science.

This book is concerned with the relationship between interdisciplinary research and information. It is based largely on interviews with scientists about how they work across disciplines to solve research problems. While the disciplinary boundaries of science are progressively shifting and dissolving, they continue to bring needed structure to the world of research by differentiating consolidations of knowledge and expertise. But, depending on the problem at hand, any segmentation scheme can obstruct communication and information transfer and deter the mobilization of

knowledge. In the practice of interdisciplinary research, disciplinary boundaries, like most other components of the research process, require a certain amount of management.

My investigation of the interdisciplinary research process focused on the strategies scientists use to manage boundary crossing information work. Studies of the practice of interdisciplinary work, as Weingart and Stehr (2000) suggest, yield more vital insights than studies that attempt to define disciplines or weigh the merits of interdisciplinary efforts. For this reason, I have not strictly delineated disciplines or tried to determine what mix of disciplines constitutes authentic interdisciplinary research. In fact, my analysis does not support any one conceptualization of interdisciplinarity, nor does it directly challenge any of the multiple ways that discipline crossing research has been portrayed in the past. Instead, I provide a close look at the practices and conditions that generate interdisciplinary science, corroborating that there are many ways that people and information move across boundaries and interact effectively during the course of complex and integrative scientific work.

It is important to note, however, that because the notion of interdisciplinary research has not solidified, debate about what it really means goes on. As Klein (1996) points out, "interdisciplinary" was included in the 1977 *Dictionary of Diseased English*, a compilation of words that had been "used with so serious a lack of precision" that they ceased to be effective for communication and serve only to "confuse or mislead" (Hudson 1977, xix). Over time, the term has become more commonplace but no less ambiguous. Other words used to describe the complex intellectual world also leave much to interpretation. We have an idea of the function of disciplines and subdisciplines—they bring order to researchers, students, methods, journals, and the like. And, while they commonly take form in academic departments and curricula, professional organizations, textbooks, and systems for classifying knowledge, it is nearly impossible to discern what exactly falls inside or outside a discipline at any given point in time.

To investigate the dynamics of interdisciplinary work, I turned my attention away from the bounds of the disciplines themselves and concentrated on the scientists and their interactions with people and materials outside their core research area. My approach makes conceptual distinctions between levels of disciplinary interaction within a loose hierarchy of synthesis. Within this frame of reference, a discipline represents the subject areas, tools, procedures, concepts, and theories of a stable epistemic community (Klein 1990). "Multidisciplinary" describes an additive juxtaposition of disciplines. For work to be considered interdisciplinary, it must bring together and synthesize material from more than one discipline. Of course, some amount of synthesis will generally take place as an interdisciplinary project is carried out, but the heterogeneity of the subject

areas involved and the degree of integration can be quite variable. Transdisciplinary, a concept that is currently receiving considerable attention, implies a higher-level synthesis. Transdisciplinarity is a means, or a way of working and acting, that produces holistic, integrative knowledge. This genre of research is problem-centered, participatory, and involves multiple stakeholders (Klein 2000, forthcoming.)

Throughout the text, I consistently apply the terminology favored by the scientists during the interview sessions. As a result, the term interdisciplinary pervades throughout the book. It clearly still resonates with scientists, and it continues to be used widely in academe to describe cross-cutting programs and initiatives. I have used the term cross-disciplinary when the process of integration is not meant to be implied to a particular situation. Since the term transdisciplinary was not part of the participants' vocabulary, it does not appear in descriptions derived directly from the empirical data.

To faithfully represent the interdisciplinary research process as conveyed by the scientists, I interweave their words with my analysis to tell the story of how interdisciplinary work happens in their research world. Chapter 1 lays out the context of interdisciplinary research locally at the research site, and conceptually as conveyed in the literature. Here I also sketch out a model of interdisciplinary research modes, a primary outcome of the study that provides structure for talking about the details of work practice. In Chapters 2 and 3, I build a narrative account of boundary crossing information work and the interdisciplinary research environment as experienced by the researchers. These data-rich chapters cover the practices researchers use to gather and use information, and to learn, build, and disseminate new knowledge. Here we also come to understand the scientists' orientations to their fields of study and the institutions and cultures in which they work. Chapter 4 covers the larger processes of research—how it happens and what needs to be in place for progress to be made in terms of both personal and organizational resources and strategies. In the concluding chapter, I discuss the implications of the multiple modes of interdisciplinary work and priorities for developing supportive environments and information systems for interdisciplinary research.

Earlier reports of this research and previous versions of some of the material in this book have appeared in the following publications: "Information Work at the Boundaries of Science: Linking Information Services to Research Practices," *Library Trends*, v. 45, no. 2 (1996): 165-91; "Ways of Working and Knowing across Boundaries: Research Practices of Interdisciplinary Scientists," in *Finding Common Ground: Creating the Library of the Future without Diminishing the Library of the Past*, edited by Cheryl LaGuardia and Barbara A. Mitchell, New York: Neal-Schuman, 1998; "Structures and Strategies of Interdisciplinary Science," *Journal of the American Society for Information Science*, v. 50, no. 3 (1999): 242-53; "The

Information Connection in Scholarly Synthesis," in *Discourse Synthesis: Studies in Historical and Contemporary Social Epistemology*, edited by Raymond G. McInnis. Westport, CT: Praeger, 2001.

I regard many people as significant contributors to this book. Most importantly, I am indebted to the scientists who participated in this research. They graciously volunteered their time, but their introspection and openness about their experiences are what made this work possible. Geoffrey Bowker's guidance and feedback carried me through the many stages of development and early drafts of the manuscript. His brilliant insights made their mark on the text, while his brilliance as a mentor endures in my researcher psyche. At several stages during the course of this project, Julie Thompson Klein provided invaluable assistance by sharing commentary, texts, and her vast knowledge in response to my queries. I am grateful to the anonymous reviewers and local readers for their many helpful comments on early versions of the manuscript. I wish to thank Linda Smith and Pauline Cochrane for their comments on the text and for urging me to pursue publication, Leigh Star for her advice on later stages in the publication process, and especially Leigh Estabrook for her sage advisement and consistent confidence in my particular blend of information science. In the final stages of production, Neil Robinson showed great devotion and evenhandedness in his attention to the details of manuscript preparation.

The years of work that went into this book have been sustained by my wonderful and generous colleagues at the University of Illinois who have shown unfaltering support and kept me intellectually engaged and in good cheer. Finally, I dedicate this book to Ed, Evan, Laurel, and Nina, who regenerate all my academic pursuits. They are my most genuine advocates and my most glorious exploit.

Chapter 1.

THE CONTEXT OF INTERDISCIPLINARY SCIENCE

If we could visually trace how the entire stock of knowledge has expanded over the past half century, the spread of the exterior boundaries and the increase in overall mass would be considerable. An equally striking change would be seen in the internal geography. Knowledge has been in a state of flux—a continual process of reconfiguration, with existing subject domains merging and seceding, and new ones emerging. As the structure of knowledge grows in both scope and specificity, the conduct of research is also changing. Increasingly researchers are importing and exporting information, techniques, and tools across disciplinary boundaries and working together to apply more powerful and sophisticated approaches to the questions they ask. They manage to continue to solve important research problems by adapting their methods of inquiry to the breadth and complexity of knowledge.

The importance of interdisciplinary research has been recognized since the Social Science Research Council was established in the mid-1920s (Klein 1996, Fisher 1990). In recent decades scholars from a number of fields have begun to take a close look at where, how, and why it is done, and to what end.[1] Path breaking ideas are said to emerge through the cross-referencing of ideas across disciplines (Turner 1991), and it has been proposed that disciplinary boundaries are the fault lines that conceal future scientific revolutions (Fuller 1988). It has even been argued that we have passed into a second mode of knowledge production, a transdisciplinary phase that not only transcends traditional disciplinary frameworks but gives rise to more socially responsible creators of knowledge (Gibbons et al. 1994). There are people who take a heterogeneous and non hierarchical approach to research, and there are places that strive to support this ideal. This book is about one such place. Through the study of scientists at an interdisciplinary research site, we will see that an organization constructed to promote interdisciplinary exchange and synthesis may, for better or worse, still be bound by perspectives and structures associated with traditional disciplines.

Interdisciplinarity is not simply about how research and education are arranged within institutions. It is not an isolated or esoteric phenomena (Jantsch 1980) but a pervasive approach to inquiry found within disciplines and outside them. "Disciplines now routinely experience the push of prolific fields and the pull of strong new concepts and paradigms" (Klein 1996, p. 56). Interdisciplinary work has become an essential part of the ongoing process of

knowledge production, "from the point of making claims to legitimating practices and judging outcomes," to forming new hybrid disciplines (57). Yet little is known about the process itself, about how information and knowledge are transferred between communities and mobilized to address research problems. How is information gathered, combined, and disseminated across intellectual boundaries? How do researchers overcome or work around the physical, social, and cultural barriers that exist between fields of research? As an information scientist, my work is aimed at understanding the processes by which people become informed, expressly for application to the design of information systems and services for particular communities of users. But, in effect, how information and knowledge are used, organized, and produced is of interest to numerous fields of study, including communication, sociology, management, and education. It is also of practical concern to individuals involved in interdisciplinary research and education, as well as universities and governmental agencies where decisions about funding and development of infrastructure for research are often made without a thorough understanding of what is necessary for research work to be performed effectively.

As new information technologies are adopted in our research institutions, it is easy to see how they can reduce some constraints, especially those that have to do with time and the location of work. There is no doubt that computers are essential tools for communication, the display and manipulation of information, the analysis of data, and the simulation of systems. Nevertheless, "integration is a human action" (Klein 1996, 218). There is no overlay of technology that can permeate the organizational, intellectual, and linguistic barriers that constrain the flow and exchange of information across disciplines. Information integration is knowledge work done by people. This book is about how a group of academic scientists manages to work across dynamic, overlapping, and mutable knowledge domains. It is about the skills, strategies, and tools they use to bring together the resources they need to work on scientific problems. Their practices and experiences reveal what is required for the conduct of interdisciplinary research, ultimately leading us to see why emergent intellectual communities, and their communication and learning patterns, are just as important as machines and money.

The dual functions of research and teaching complicate the academic research environment, creating a tension that causes both fragmentation and integration (Clark 1995). As research becomes more interdisciplinary, current academic subject frameworks become increasingly ill suited to how research is really done. The disciplines may still be adequate for coordinating teaching activities within a university, but they are misleading simplifications of research areas and the intellectual domains that sustain them (Geertz 1983, Becher 1990, Pinch 1990). Interdisciplinary research centers are one of the various types of physical and administrative frameworks constructed within universities to realign the skew between academics and research. The site for

this study, hereafter referred to as "the Center," is an institute of this kind. It is a well-supported unit at a large public university with programs spanning the physical sciences, engineering, computational science, the life sciences, and the behavioral sciences. In 1995, when the bulk of the data was collected for this study, nearly two dozen academic departments, ranging from physics to anthropology, were represented in the faculty membership. At the Center, then and now, interdisciplinarity is not only accepted, it is expected.

The Center was founded "on the premise that reducing the barriers between traditional scientific and technological disciplines can yield research advances that more conventional approaches cannot."[2] This tenet was the basis for both the architectural design of the building and the assemblage of research groups. The facility, funded by an alumnus donation and state appropriations, is the second largest, and, in many ways, the most impressive building on the campus. There are two main wings: one with more than 200 offices, and a second laboratory wing with state-of-the-art computing, simulation, visualization, laser, and magnetic resonance technology. The two sections are connected by a series of bridges above a public atrium. There are public spaces for more casual group interaction, and ample meeting rooms for formal gatherings and conferences. The physical layout and the programs encourage open exchange of information, as do the many national and international workshops and conferences hosted by the Center. The facility was engineered to offer what one administrator called "bold communication possibilities."

When the study was conducted, the Center's research force was made up of approximately 150 faculty members; dozens of visitors from other universities, government, and industry; countless postdoctoral fellows, graduate and undergraduate students; as well as a full line of administrative, computing systems, and support staff. In addition to the group of researchers I interviewed for the project, I was able to enlist other participants, including an administrator and an artist in residence. Throughout the text I refer to them as the Organizer and the Humanist. The Organizer contributed detailed information about the Center's intended goals and early development, and the Humanist gave valuable interpretations of the research environment from the perspective of an informed outsider. Most of the analysis in the chapters that follow is presented from the researchers' point of view. Here I give a preliminary introduction to the Center from the unique perspectives provided by the Organizer and the Humanist.

The Organizer

> I've always thought of this thing as a big experiment. Just put something there at time equals zero, turn it on and let's see what

> happens. Some people fall out and some people come in . . . let it run a while and watch to see what happens.

The Organizer was an instrumental figure in the conception and realization of the Center. He played a key role in developing the initial proposal and in planning the building. After the Center opened, he was involved in its administration for more than five years. The primary goal of the Center was "first class research as judged by the people that work in the field and by the peer review process." His original vision was of a place unrestricted by departmental barriers, "a big, happy playground," where people could mix and learn new things. In retrospect, it didn't turn out exactly that way. For instance, he had expected that the cafeteria would be full of people having lunch and telling one another about their research, but on most days the lunch crowd comes from outside the building, and the Center members who are there tend to sit in the same groups. He had also been excited about the cross-disciplinary seminar program that was implemented, but attendance proved to be consistently poor. He discovered that "people don't come in droves to hear very general, broadly interesting talks." They are just too busy. Although all his hopes for the Center did not come to pass, he remains convinced that it *does* work, just "not at the high powered, ideal level that you might think."

The initial research programs were drawn from a pool of proposals submitted by "self-organizing groups" on the campus. Those selected fit with the original mission of the Center that was aimed at linking the efforts of researchers in many disciplines who were engaged in the quest for a better understanding of complex systems. The explicit mission changed over the years. Later promotional materials were less specific about the target areas of research, stating that the Center's goal is "to foster interdisciplinary work of the highest quality in an environment that transcends many of the limitations inherent in traditional university organizations and structures." This is a better representation of how the initiative unfolded. The planners were seeking broadly interdisciplinary groups that "spanned more than one area" and included faculty from multiple departments. Groups also had to demonstrate that the Center would add value to what they hoped to accomplish. The Organizer admitted,

> We were not completely successful. Many of the programs we chose were not really all that interdisciplinary but had the potential for reaching out and taking advantage of this opportunity to interact with these other groups.

Some were multidisciplinary in their composition; others were subunits of an academic department.

The Organizer expected that bringing together a collection of interdisciplinary research programs would produce longer range intellectual connections between them. The Center would provide the structure, encouragement, and status necessary to move the existing groups to another level of interaction, but it was not intended to be a permanent home for any programs or faculty. The membership was to change depending on who could benefit most from the facility, and, in turn, who could contribute the most to the mission of the Center. Not surprisingly, it was difficult to manage this rolling membership system.

> It's not something that spontaneously works. . . . All the manager can do is try to create an environment that is sort of proactive in stimulating these things, providing such inducements as can be provided through allocations of resources, but not with a heavy hand.[3]

Subsequent administrators have worked to make the overall research agenda more focused by defining general areas of research activity, a move that provides more thematic structure while maintaining the initial emphasis on cross-group contact and long range connections between disciplines and specializations.

The Humanist

> There is still that element . . . where you say, well what *is* the common denominator? How *do* you get these privileges and these resources? Who gets to play and who doesn't?

The Humanist was the first person appointed to the Center who did not have some kind of "quasi-mechanical" relationship with the facilities. Known to be a "cross-boundary freak," he was not out of place at the Center but was pondering the same question as many working in the neurosciences and artificial intelligence—what is the shape of knowledge? The artist in residence position was served up to him "as a free sample," and as a regular member of the institution he was able to take full advantage of the available resources. He was intrigued by the prospect of working in a place that promoted interdisciplinarity. The environment provided both stimulation and seclusion—qualities also appreciated by the scientists. The opportunity to do creative work in an isolated "playground" was most inviting. It is interesting that both the Humanist and the Organizer used the playground analogy to describe the Center. I do not know where the metaphor originated, but according to the Humanist, it never surfaced in conversations between him and the Organizer.

The work the Humanist completed while in residence was greatly influenced by the Center's atmosphere, rich with impressions of the place, the people, and their activities. At night when it was quiet, he liked to roam the halls to experience the sounds and "study the posters about nerve cells and microchips." Then he would go to his office to work at the computer. At official social functions he was an outsider, the token humanist. His struggles to converse with his Russian officemate and other encounters with scientists felt like "exercises in coherence," but they were not unlike the communication difficulties he observed between different scientific groups within the Center. Over time, and with the help of some of the scientists, he learned the "local colloquial" necessary for coherent exchange of ideas in the "community." As we will see, this scenario is very similar to the researchers' experiences with disciplinary vocabularies.

At the beginning of his time at the Center, the Humanist thought of it as a self-contained "city within a city." It had everything to attend to both physical and intellectual needs, including food, a library, and "any number of people with beds in their labs or offices." The Center seemed to house a separate population, a group not completely assimilated into the rest of society. Approaching the building from different directions on his way to the office, he was struck by its strong barrier quality and its "territorial, archaic feel." It gave him the sense that people behaved differently beyond those walls. Comparing it to other parts of the campus, he recognized the "inequitable privilege" of having an office there.

The Center, with all its new possibilities, brought on an instant change in the Humanist's sensibility; it had the ability to "uncramp." This feeling came partly from the material advantages of being a member, but it was more than that; it was exciting in unexpected ways. Just looking at all the new fields of study listed on the main entrance directory was stimulating. After having moved back to the part of campus populated by the humanists and social scientists, he observed: "these [new fields] are the kinds of things they try to buffer us from on this side of campus." He was sensitive to the indirect influences within the Center, those things that "buzz in inaudible frequencies," like the directories or the titles on the lecture announcements that get put in the mailboxes each week. "Why can't people in the humanities departments get those fliers and be thinking about those titles?" Another distinct and impressive change for the Humanist was the Center's flourishing scientific apprentice system that seemed to allow graduate students to guide the direction of research. He noted that students' roles were quite different on the "other side of campus."

Over the course of our first discussion, the Humanist referred to the Center as a city, an orchestra, a living organism, cognition, and the chef's special. Reflecting on these descriptions in our second meeting, he settled on

the organism as the best analogy because it acknowledged the importance of the lives of the individual cells.

> The orchestra metaphor would probably be more accurate if we restricted it to the three or four minutes of tuning up. Everybody is making noise, but nobody has come out to tap on the podium yet. The chef's special is for when you want to be cynical . . . an excuse to throw more money at people in an ad hoc way.

He also favored his original "city within a city" image because it exemplified the level of activity and the mix of "all kinds" of people. On the individual day-to-day level, it appeared to him that what the scientists do may not be that different from what they have always done. The overall organism, however, represented something quite significant—progress toward "hierarchical convergence" in science, an attempt "to reintegrate the reductionist program" through a "convergence of model making."

CONCEPTUALIZING INTERDISCIPLINARY INTERACTION

The interdisciplinary reconfiguration of knowledge has been portrayed in many ways: conjuring images of overlapping, blurring, displaced, and shifting boundaries; merging, fusing, and intersecting domains; and mingling and migrating individuals (Campbell 1969, Mulkay 1974, Chubin 1983, Hoch 1987, Klein 1993). None of these descriptions completely explains all the levels of activity and the interplay between people and scientific communities at the Center. A comprehensive account would document the expanding knowledge base of individuals, the creation and distribution of knowledge within institutions, the embodiment of knowledge within intellectual communities, the transfer of knowledge between these entities, as well as the vital role of information throughout these processes. We can begin to formulate a general framework for understanding interdisciplinary research by bringing together some of the key concepts that have been used to represent how knowledge domains interact and coalesce. The concept of *knowledge units*, applied in relation to the *core*, *scatter*, and *hybridization* of knowledge, effectively illustrates the social and intellectual exchanges and reformations in the general landscape of knowledge. The reconfiguration of knowledge can also be understood at the level of research practice, as a cycle of knowledge *accumulation* that involves *boundary work* and *boundary objects*, research activities and materials that expedite the process of knowledge accumulation.

Fisher's (1990) notion of knowledge units is useful for thinking about the intellectual interaction involved in cross-disciplinary inquiry. Building on

work from the sociology of knowledge and sociology of education, Fisher conceives of integrated knowledge as weakly classified units with flexible boundaries that allow open exchange between people.[4] The scope of a knowledge unit is variable; it can be "a discipline, a subdiscipline, or a group of disciplines" (98). For example, general classifications such as mathematics and engineering are typical disciplinary knowledge units, whereas optics is a smaller unit within physics. Integrated knowledge may be an agglomeration of disciplinary, specialized, and fragmented units, but the various units must exist in open relation to each other. Extending this idea to interdisciplinary knowledge, an integrated cross-disciplinary field will have a core of knowledge that is made up of multiple, interdependent units. The units may be disciplines, subdisciplines, or less developed subject areas, and some or all of these units may be equal in emphasis. Interdisciplinary fields evolve and integrate over time as researchers work with, exchange, and synthesize knowledge from multiple units.

Studies of scientific communication suggest that knowledge units interact and influence each other through scatter (Chubin 1976). Drawing on Crane (1969) and Bradford (1953), Chubin asserts that without the scatter of knowledge, scientists would be isolated in small groups that only speak to, read, and cite each other. Even scientists who work from a highly disciplinary core draw from the periphery of their domains, deriving "innovations from the margins" (448). Knowledge development within the core promotes growth and cumulation, and scatter outside the core keeps science from being "a sect-like phenomenon" (Crane 1969, 349). While fragmentation and scatter can inhibit the general "utilization" of knowledge (Beam 1983), they are essential for the discovery and innovation that stimulate the growth and evolution of knowledge.

Dogan and Pahre (1990) propose that knowledge is reconfigured through a "specialization-fragmentation-hybridization" process whereby knowledge units merge and develop into various informal and institutionalized structures. Informal hybrids can take the form of cross-disciplinary research topics or networks of interpersonal contacts. More permanent institutionalized hybrids are realized in cross-departmental academic programs, emergent fields of study, and interdisciplinary research organizations. The field of psychology can be thought of as a conglomeration of hybrids that includes social psychology, physiological psychology, political psychology, behavioral pharmacology, and cognitive science. In particular, cognitive science, which draws from linguistics, computer science, neuroscience, and philosophy, illustrates psychology's interconnections with outside fields (Dogan and Pahre 1990). Biophysics is another obvious case. Physics tools have been involved in the investigation of biological problems since the development of the optical microscope. Today, theoretical physics is fundamental to biological studies of proteins, genetic materials, and the multicellular organization of the brain

(National Research Council 1986). Cognitive science and biophysics are among the more highly developed scientific hybrids, as evidenced by their strong presence at the Center and within the schema of conventional academic departments. They have been firmly classified in structures of knowledge and research. Many newer, evolving interdisciplinary areas, such as environmental studies and urban studies (Klein 1996), do not yet have a stable place in categories of knowledge or institutions where knowledge is produced and disseminated.

The core and scatter dynamic represents the intellectual distribution and circulation of knowledge, while hybridization depicts the conflation of knowledge as manifested in institutions and organizing structures. These concepts are useful for tracking and interpreting the shifts and changes that continually affect disciplinary relations. Cores of knowledge have established boundaries in organizations and systems of categorization; scatter moves knowledge beyond the perimeter of those boundaries; and hybridization reconstructs the boundaries. More palpable than these abstract notions, however, are the hard work and the obstacles that are a substantial part of interdisciplinary research. The term scatter, in particular, suggests something much more random than the very deliberate and directed activities performed by the scientists at the Center as they transfer ideas, information, and themselves across boundaries. In their day-to-day work the scientists set priorities and develop routines that help them to move beyond their core into other domains to gather and distribute the wares of research.

The research processes that build interdisciplinary knowledge involve core development, scatter, and hybridization. As Latour (1987) demonstrates, a working definition of knowledge must be based on an understanding of what it means to gain knowledge.

> Knowledge is not something that could be described by itself or by opposition to ignorance or to belief, but only by considering a whole cycle of accumulation: how to bring things back to a place for someone to see it for the first time so that others might be sent again to bring other things back. (220)

Latour uses the example of expeditions by early French navigators to illustrate the nature of accumulation. The navigators gained what they needed to know for their travels through "kings, offices, sailors, timber, lateen rigs, spice trades, and a whole bunch of other things not usually included in 'knowledge.'" The navigators' cycle of accumulation included all the actions and interactions, exchanges and negotiations, objects and people that made it possible for them to carry out their work and document it in enough detail for someone else to follow their route at a later time. The next expedition would be charted—the water, the land, and the natives would no longer be unknown.

Knowledge accumulation in the practice of research is similarly dependent on a range of actions and interactions, exchanges and negotiations, objects and people, many of which are taken for granted or not easily observed.

Latour emphasizes the things within the knowledge cycle that enable information to be moved and combined, because they accelerate the accumulation process. Map making, printing presses, engraving of plates for scientific texts, projection systems, classification schemes in libraries, and, of course, computers work in this capacity (228). This relationship between the mobilization of information and the accumulation of knowledge is particularly salient in the context of contemporary research where networked computing environments allow information to be readily transferred and transformed. Information technologies are changing how information is moved and used, and for interdisciplinary scientists who need to accumulate knowledge from multiple disciplinary worlds, they offer new avenues for gathering divergent information and working across boundaries.

Gieryn's (1983, 1995, 1999) extensively developed concept of boundary work relates to the scientific practices that construct the social boundaries that separate science from everything else. Boundary work, in this sense, "is a strategic practical action" performed to monopolize, expand, and protect science (Gieryn 1999, 23). Fisher (1990) applied the idea to scientific activities more broadly, defining boundary work as "acts and processes that create, maintain, and break down boundaries between knowledge units," acknowledging, as does Gieryn, that it simultaneously "involves institutions and social structures" (98). Klein (1996) also extends the idea of boundary work beyond the role of demarcation to cover how boundaries are permeated and dismantled. In the context of interdisciplinarity, Klein defines boundary work as the

> . . . composite set of claims, activities, and institutional structures that define and protect knowledge practices. People work directly and through institutions to create, maintain, break down, and reformulate boundaries between knowledge units. (p. 1)

Their activities "attribute selected characteristics to particular branches of knowledge on the basis of differing methods, values, stocks of knowledge, and styles of organization" (Klein 1993, 185-186). Adopting Fisher's emphasis on knowledge units and their malleability, this variation on the concept of boundary work accounts for the professional authority and expertise central to Gieryn's conception, while capturing the crossing and reconstruction of boundaries that takes place as researchers break out of established domains to create new knowledge. My analysis is largely focused on the information and communication functions required for crossing boundaries in the accumulation process and on the specific resources and activities in the research environment