Information Work at the Boundaries of Science: Linking Library Services to Research Practices

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ABSTRACT

BEFORE INFORMATION PROFESSIONALS CAN BEGIN to improve existing services in research libraries, they need to understand the information work involved in the research processes of contemporary researchers. In the sciences, research is becoming more broadly based and collaborative and, increasingly, information, techniques, and tools are being imported and exported across disciplinary boundaries. This article examines the information practices and strategies used by interdisciplinary scientists as they perform "boundary work." As researchers gather and disseminate information outside their core knowledge domains through personal networks, conferences, and the literature, they interact with objects, methods, people, and words. Much of their information work is devoted to probing and learning in new subject areas, and they often rely on intermediaries to help collect and translate material from unfamiliar territories. Libraries that wish to facilitate cross-disciplinary inquiry will need to design information environments that support learning, provide tools that function as "boundary objects," and offer intermediary services that assist in the transfer and translation of information across scientific communities.

INTRODUCTION

Over a decade ago, Clifford Geertz (1983) observed that the lines separating scholars "are these days running at some highly eccentric angles" and that disciplinary categories no longer reflect how people think about things and write down what they think (pp. 6-7). Established disciplinary frameworks bear ever less resemblance to the way researchers

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and scholars work and group themselves, obscuring the actual composition of intellectual communities. Who really talks to whom through the scholarly and professional literature and through other formal and informal means may, in fact, have no common factor other than the problems being addressed.[1] Researchers who work across disciplines often have a wider topical orientation than those addressing problems from a disciplinary perspective. Clearly, this complicates the research process, and researchers must take steps to manage this complexity.

As research and knowledge become more interdisciplinary,[2] the academic subjects represented in our research libraries become increasingly ill-suited to the conduct of research. They are becoming obsolete for the research activities that create knowledge (Pinch, 1990) and for organizing the products of research. Library services, collections, information tools, and criteria for allocating budgets often do not account for interdisciplinary and emerging fields of study (see Searing in this issue of *Library Trends*), at least not until they become part of the formal curriculum. However, before information professionals can begin to improve existing services or develop new approaches that account for the complex needs of contemporary researchers, they need to understand the activities and patterns involved in the cross-disciplinary research process.

Librarians are participants in the networks of research activities and are responsible for helping to advance the research process. With researchers and scholars extending their range of inquiry into multiple disciplines, fitting information to the needs of the individual becomes a greater challenge, in part because interpreting the user's world[3] is much more difficult. Once we understand the information worlds of contemporary researchers, reference librarians, managers who organize and implement service programs, bibliographic compilers, and designers of information systems and collaboratories may be able to build information environments that are more supportive of cross-disciplinary research.

Approach

User studies within library and information science have provided important insights into the information-seeking behavior of researchers, but the groups studied have generally been discipline based.[4] Studies of interdisciplinarity have tended to examine disciplinary relationships as reflected in the content of literature, with citation analysis being a favored method of study.[5] Much of this work has focused on the import of information and ideas from one discipline to another.[6] These studies have offered sufficient evidence that cross-disciplinary inquiry is practiced and to a significant degree. We know little, however, about how discipline-crossing research is conducted or about how information is used in the process.

My recent study of scientists at an interdisciplinary institute (Palmer, 1996) combines quantitative and qualitative methods to gain an understanding of the practices and conditions involved in the cross-disciplinary research process. After identifying a sample of boundary-crossing researchers through citation analysis methods, interview data were collected and analyzed to explore how researchers gather and disseminate information in multiple knowledge domains. Based on results from that study, this article examines the discipline-crossing information practices and strategies described by highly interdisciplinary scientists. They are members of a research organization (referred to hereafter as "the Center") devoted to the study of "living and non-living systems of increasing complexity." The Center houses research programs that span the physical sciences, engineering, computational science, the life sciences, and the behavioral sciences. My approach follows a recent trend in studies of science where work is examined within an institutional niche.[7] Labs, institutes, and departments provide a context for examining practices within the user's local organizational and social environment.

Chubin's (1976) notions of "core and scatter" are useful for understanding the dynamics of knowledge within the research process. Disciplines are centered around an intellectual core and, at the same time, they overlap through scatter. Drawing on research done by Crane (1969) and Bradford (1953), Chubin asserts that, without scatter, scientists would be divided into small groups, only speaking to each other and reading and citing each other's work. Knowledge development within the core permits science to cumulate and grow, and scatter (communication outside the core) keeps it from becoming a "sect-like phenomenon" (Chubin, 1976, p. 459, citing Crane, 1969, p. 349).

The researchers at the Center cross into areas outside their knowledge core, interacting with information and people from other domains through "boundary work." Gieryn's (1983) initial conception of boundary work emphasized the boundaries that separate science from everything else. Fisher (1990) later applied the idea to the boundary-crossing activities involved in interdisciplinary science. As the scientists at the Center cross boundaries, certain elements assist with their work. According to Star and Griesemer (1989), "boundary objects" help people come together to solve problems by inhabiting "several intersecting social worlds" and satisfying "the informational requirements of each" (p. 393).

While boundary work has been defined as the cooperative pursuit of tasks in spite of boundaries that could prevent separate social worlds from achieving goals (Gieryn, 1995), many researchers at the Center practice types of independent boundary work. Individual efforts to traverse multiple disciplinary worlds do not seem to be as productive as cooperative pursuits, however, unless there is a focal point or a vehicle that fits the informational criteria of a boundary object. For example, reading the published research literature, in general, is not a very effective way of crossing into another discipline. On the other hand, a particular conceptual essay, an author who is a talented communicator, or a single analogy can be instrumental in moving beyond interpretive barriers to make use of material from an outside subject area. In general, literature, methods, data, and results can serve as boundary objects, but colleagues, students, machines, and concepts seem to function most effectively in this role.[8]

An Overview of Boundary Elements

Physical objects can be the focal point of a boundary-crossing activity. Data (numbers) and data sources (rabbits) are shared between labs and sometimes brought together for comparative analysis. Banks of raw data are amassed and then added to by allied researchers. Molecules built by one research group may be analyzed by another, with both sides bringing insights to the final results. It is common for one lab to borrow apparatus from another community of scientists and apply it in new ways and to different types of data. New computational technologies are often combined with established disciplinary science to "push the frontier end of studies" in a problem area. Computer modeling has helped to break down the boundary between experimental and theoretical work, but the computer's role between disciplinary boundaries is less clear. At the very least, sophisticated computation may enable boundary crossing by producing models that can be applied broadly across sciences.

Methods move across boundaries in a number of ways. Researchers bring techniques and procedures from a variety of disciplines to their research problems. One psychologist listed the following measures as part of his investigative repertoire for just one of his two major research areas: reaction time and accuracy measures from cognitive psychology, event-related brain potentials from neuroscience, and magnetic resonance imaging from physics and chemistry. Several other cases illustrated how experts use their methodological training in one discipline as a point of entry into another disciplinary domain. For example, a computational neuroscientist learned computer modeling and simulation as a physicist. He later transferred these skills to neurobiology, where he currently contributes to the experimental side by building on his electronics experience, while using his physical science expertise to address theoretical questions.

People are involved in every aspect of cross-disciplinary work. "The big guys" loom over disciplinary territories long after they die, influencing the direction of science through their followers.[9] Colleagues give researchers a sense of place or belonging, and personal contacts continue to be one of the most important vehicles for transferring information across borders. Students play a versatile boundary role by functioning as human conduits for the passage of information. They are traded between labs, used as translators between theoretical and experimental work, and sent as emissaries to other parts of academia and out into industry.

Words can also be the meeting point for different sciences. Metaphors act as models, creating new frameworks for addressing scientific phenomena. Several researchers talked about using metaphors as tools to help groups of people from disparate backgrounds think about a problem in the same way. Words and concepts cross borders and, over time, the vocabularies of different communities change and merge. As certain terms become more broadly applicable, there is more cross-communication between disciplines. A bioenergetics specialist gave the example of how the terminology used by a biologist working on charge separation may gain the attention of physicists interested in electron transfer as well as chemists working in catalysis who are interested in protons. The exchange of words seems to depend more on reading than writing. Many researchers try to read across disciplinary boundaries, while few make large leaps in their writing and publishing. Words are, perhaps, the most tenuous of boundary elements. They can generate cross-disciplinary understanding, but at the same time they create serious impediments to communication between scientific cultures (Palmer, 1996, in press).

Ways of Working across Boundaries

The researchers at the Center are not particularly comfortable with any categorization of what they do. From their perspective, their research is not disciplinary, multidisciplinary, or interdisciplinary; it is "problem-centered."[10] As a theoretical physicist explained:

> The world doesn't know about physics, chemistry, and biology. The world's problems developed independently of them, so to solve them you really have to try to go at it from all angles.

The strategies used by researchers to gather and disseminate information across disciplinary boundaries are constructed around the problems they address. Beyond this common problem-centered approach, the information practices of interdisciplinary scientists are varied and complex. In their attempts to "go at it from all angles," they "accumulate" knowledge in many ways.[11] They import and export information through formal and informal channels; apply individual and group approaches; and take advantage of written, oral, and electronic information formats.

Information probing is an important type of information work for cross-disciplinary researchers at the Center. Probing is investigative in nature and takes place outside of the scientist's core knowledge domain. Researchers probe broadly to increase their breadth of perspective and to generate new ideas. Skimming through a wide range of journals and general science magazines, hoping to latch onto a new idea, is a probing activity. Researchers also probe deeply to explore or upgrade their knowledge level in peripheral subject areas. For instance, one scientist attends an intensive workshop in an outside discipline on a regular basis for this purpose. While all the researchers were concerned about the difficulties in finding and keeping up with information, particularly in subjects outside their core research area, probing was discussed as an important cross-disciplinary information strategy. However, since probing can lead to an expansion or shift in research interests, it may further complicate a researcher's information work by altering the scope of relevant subjects to search and changing where pertinent information will be found. Moreover, with each new domain, there are new terms and concepts to learn and analytical approaches to understand.

Cross-disciplinary researchers may work with information differently than more discipline-based information users, but the general sources of information appear to be much the same. The researchers rely on both formal and informal channels for gathering information,[12] depending primarily on personal networks, conferences, and the published literature. As they work to move into new knowledge domains and overcome disciplinary barriers, there are serious challenges to overcome. The researchers need to make sure that they spend their time and effort targeting relevant material and making the right contacts in outside fields. None of the scientists was at ease with the process of importing or exporting information across disciplines; it was a practical and intellectual challenge for all. Experienced researchers feel like novices as they look for information in unfamiliar contexts and attempt to become oriented and knowledgeable in new subjects. Two information work patterns were particularly trenchant: the gathering of information as part of a learning process and the reliance on intermediaries to help manage the collection and translation of information across boundaries.

Networks

> "Normally, maybe 85 percent of what is going on
> I just know by keeping in contact with people
> and by going to our own conferences"—device physicist

For researchers at the Center, personal networks are the most important vehicle for information exchange. Colleagues and students are rich sources of information because they are efficient and yield quality results. This is consistent with other studies of scientific communication. Conversations and correspondence have been found to be important methods for exchanging news and getting feedback on preliminary work (Garvey & Griffith, 1968; Griffith & Miller, 1970). In cross-disciplinary research, feedback from knowledgeable sources is crucial because of the uncertainty involved when venturing into unfamiliar domains.[13]

Conversing with people in allied fields makes researchers aware of their own knowledge gaps, and establishing personal contacts in other fields promotes cross-disciplinary understanding and integration.[14] Researchers consult with contacts from different backgrounds to explore the various ways a problem can be approached, to grasp the long-term hopes for a solution, and to learn how their research relates to other work on the problem. The exchanges that take place in these multidisciplinary networks constitute small, yet crucial, steps toward scientific convergence. A vision specialist used the metaphor of a huge interactive database to illustrate how two people from different disciplines converge on relevant information about a problem.

> "Someone will say, Oh, this guy did something, so and so, you should look at his paper. This will happen after they have summarized the significance of that, which they did not know until I told them what I was looking for. So it's an interactive search for the right thing. They have their own huge database and, if we talk, then we are converging on the right references or people.

The interactive process narrows down the discussion to a specific concern and centers it within the perspective that is needed.

Researchers who do a lot of information probing are frequently faced with the task of sifting and evaluating all the ideas and "pet theories" that they come across. Personal contacts from outside fields are called on to evaluate the viability of newly discovered ideas and approaches from unfamiliar domains. Connections are established based on shared interests and tend to be made with trusted colleagues who have the authority to help evaluate information. Even researchers who prefer reading about emerging areas of interest almost always follow up by discussing particulars with network members. Information gleaned from an outside body of literature can be turned into usable knowledge by discussing it with someone from the other field.

As might be expected, e-mail has been welcomed for managing the exchange of information within personal networks and for collaborative work. E-mail was talked about as an indispensable part of the research process. It is used "perpetually" as the primary means for keeping in contact with colleagues. It has made a real difference for two activities in particular: planning and collaborating. It is how researchers "get organized—arrange to do this and that." It is especially appreciated for editing and cooperative writing projects. Researchers can keep in touch with many authors simultaneously and compile and edit texts at a pace that suits their schedule.[15]

Conferences

"If it weren't for conferences I really would be lost"—photosynthesis specialist.

"Everybody who matters is there and for a week you
get saturated in this stuff. For what I am doing,
I have to be at that conference"—complex systems chemist

While the large discipline-oriented conferences were rarely mentioned by the researchers, small specialized meetings were considered by many to be as critical as personal contacts for keeping up with information. The most valued meetings are those that congregate at the problem level, where researchers feel part of a "closely knit group" that shares specific research interests.[16] In fact, it seems that, for some researchers, these meetings are an extension of the information exchanges that take place with network members and, like those networks, the conferences satisfy a multitude of information needs. According to a neurophysiologist, "you kill a lot of birds with one stone; you get the social interaction, you get the professional interaction, and you get the references [to the literature]." The meetings provide the efficiency, focus, and interpersonal aspects of personal networks, held physically captive for days. In addition, this framework for intensified exchange is an ideal setting for establishing new connections with people who can enhance one's personal network.

People met at specialized meetings may become future research partners. Finding collaborators seems to be a natural part of the act of assembling and talking about research.

> The way it happens is by finding the people just in the normal sort of processes of social intercourse at meeting. "You find the people who are talking in a way which you have some affinity for, the people who are making an effort. And then you talk to them and, after awhile, you get to know them well enough so that you can ask them stupid questions without feeling really idiotic. And really, there are some people who turn out to be just absolutely wonderful expositors of complex ideas—people who themselves have thought about, you know, why am I doing this? And you latch onto those people (bioenergetics specialist).

The bioenergetics specialist has seen a tremendous influx of theoretical physics, computational studies, and both theoretical and experimental chemistry into biological protein research. It has become a "real melting pot." Understandably, at events with very diverse populations, cross-cultural issues come into play. This scientist described one of her regular meetings as "a bit like a convention at *Star Trek Deep Space Nine*.[17] There are all sorts of different species around, some of whom can't talk to each other, no doubt about that." Overall, the communication difficulties encountered at conferences seem to be much less frustrating than those faced in the literature. As with other person-to-person information activities, the element of exchange brings value to the information—discussion is productive and satisfying research work.

The type of information acquired at conferences can be quite different from what appears in the published literature. A computational neuroscientist attends conferences to get in touch with "the undercurrent."[18] The information he gathers is especially valuable because it is "raw, not polished—because it is speculative" with no deep ideas attached to it.

Hearing about "pieces of data that people don't quite know how to put together yet" offers a different kind of intellectual stimulation than the seamless research reports published in journals.

Literature

> "If you can't look at far more literature than anyone has time to look at you get into this tiny little corner where you keep reinforcing your preconceived notions"—complex systems chemist

This quote brings together two of the most prominent characteristics of literature for cross-disciplinary information work. First of all, there is much more to read than anyone can possibly keep up with. The sheer magnitude of potentially relevant material seems insurmountable.[19] Literature dispersion is the other distinctive problem experienced by these researchers. The chemist, who recently shifted from a specialization in chemistry instrumentation to complex systems research, explained:

> There was a time not that long ago when I could go to the physics library and walk from one end of the shelves to the other and inside of a half hour see everything I needed, and be pretty sure I hit everything that mattered, because I knew what journals it was going to be in.

In the past, searching electronic databases had been productive as well, because one's interests could be covered in "only about ten keywords." There are so many sources and terms that relate to his current problem area that his old reading and searching routines are no longer adequate. Moreover, he claims that the increase in subject scope has made it too expensive for him to have literature searching done by a commercial service.

The Internet has made the dispersion problem even more frustrating for the complex systems chemist. He compared the chemistry information available through the Internet to the state of chemistry literature before *Chemical Abstracts* began.

> It doesn't matter how marvelous the stuff is that is out there if you can't get at it—except if somebody says, By the way, I was talking to a guy when I was at a conference last week and he says that if you go onto this computer here you can find an address to go to that computer over there, which supposedly will tell you of another place over there where you can get what you want. Now what kind of nonsense is that?

In fact, this scientist was one of the few who emphasized the importance of electronic networks for functions other than e-mail. For most researchers, electronic formats did not seem to be included in their conception of literature. The subject did not naturally come up in our discussions of literature use, and when asked specifically about it, the responses were very limited. Many commented that they "should" or "wished" they could take advantage of available technologies for finding or exchanging information and documents.[20]

Despite the problems identifying and accessing dispersed literature, reading continues to be an important information practice for most of the researchers, yet there were a few who claimed to not read at all or only rarely. Many researchers described a type of broadly based reading, geared toward the infusion of new and more generalizable knowledge:

> "What I read in the literature—I mean the research literature—I think is generally much broader than most people in my area. And I think that really has helped feed into—I mean, it gave me knowledge of just the way proteins in general function rather than keeping me very focused, and rather narrowly so, on what was being considered by the central part of my field. And I think that it did give me some ideas as to what might be happening that wouldn't have occurred to me otherwise" (bioenergetics specialist).

Broad reading can help maintain a cross-disciplinary edge and sustain a wide perspective, developing new interests, and opening "broader vistas." However, researchers who read broadly do not necessarily read carefully. Some recall a time when they had been able to read entire articles and some journals cover to cover on a regular basis. Now, documents are usually skimmed rather than read. In fact, a 1992 survey of researchers at the Center revealed that 83 percent of the respondents tended to skim literature instead of read it. Larger bodies of literature are browsed.[21] As precious as time is to these scientists, the potential for discovery is great enough that browsing is worthwhile. The researchers browse to gather information and to probe new and peripheral areas. One researcher commented that he has found significant works by scanning contents pages at bookstores and at publisher's displays at conferences. Some scan vast amounts of literature hoping to "trip over something by accident"—a reference, a mention of an idea, or a vein of thinking that might be important to their work. One researcher explained: "You can't narrow things too much in the hopes that you are going to catch something. You've got to keep that peripheral vision up." Some browse electronically but, in general, the electronic databases seem to be relied on more for finding information about something specific. Only a few researchers placed much importance on the bibliographic databases available in the campus libraries and on the campus electronic information network. The 1992 survey of researchers at the Center showed that 43 percent never used the electronic abstracts or indexes available in the campus libraries and 62 percent never used them from their office or other campus sites.[22]

Broad conceptual and "summary books" that take a comprehensive view of science are important to some for the insights they provide. General and comparative journals were also emphasized, and multidisciplinary titles like *Science* and *Nature* were cited as regular browsing and reading material. A molecular network specialist reads *Scientific American* religiously because it enables him to "dip into things like software design and immunology," things that he has "a smattering of knowledge about." Then, once the vistas are opened, it is time to "put on your boots and slog through the literature." Once researchers move outside their core, reading feels more like slogging because the content and terminology are less familiar. A specialist in an area can easily skim titles and abstracts; a novice will need to spend more time and read deeper to determine what information is relevant.

The journal literature can be useful for keeping current if there are publications that concentrate on the right disciplinary intersections. For a neurophysiologist, *Neural Networks* is a key journal because it covers research on a wide range of scientific processes. This same title is also a primary source for a psycholinguist, who has a very different subject orientation. A protein specialist praised the changing profile of journals over the past ten or fifteen years. Many new titles have appeared that are intended to fit cross-disciplinary audiences. In his research area, the journal *Proteins* has become influential. The title would also interest biophysicists working on membranes, biologists in photosynthesis, and physicists doing drug design, among others. For network modelers in biology, psychology, physics, or physiology, *Biological Cybernetics* is an important publication. The combined practice of browsing both the general multidisciplinary titles and the more specialized cross-disciplinary journals provides an important balance of breadth and depth, both of which seem necessary for interdisciplinary progress.

Cross-disciplinary review articles can supplant extensive and difficult information gathering.[23] Research reviews offer packages of collected, filtered, and partly synthesized information. They function as successful boundary objects because they are integrative in nature, representing an intersection of multiple scientific worlds. They can provide the references needed for a concise introduction to a research area or a way to catch up on work in a peripheral subject. Review writing is practiced occasionally, although there are not many incentives for scientists to take on this type of project. "There is some feeling that anybody can write a review, but it takes a real first rate scientist to do experiments."

Learning

> "Every good research group strikes a good balance between learning and doing. Even a seasoned researcher must keep a good balance of learning"—theoretical physicist

For many cross-disciplinary researchers, learning is a significant part of the research process and the intention behind many information-seeking activities. Knowledge development is time consuming for the scientists, and it is difficult. Most were very cognizant of their limited capacity to learn new material, especially at the level necessary to enhance problem solving. They felt the "burden of comprehension" inherent in interdisciplinary work (Klein, 1990, p. 110). The more subject areas a scientist spans, the greater the burden, and the work is especially taxing because the researchers are not just responsible for specifics that are borrowed from another field. They must also understand the history, surrounding context, and the current status of the material. White (1987) maintains that any meaningful crossing of disciplines "must take place through a process of translation that is based upon rather full knowledge of the practices that define each community" (p. 11). Researchers must understand theory, technique, and particulars.[24]

Learning is often the explicit goal of probing, as when researchers explore general and multidisciplinary literature to expand their knowledge base or attend workshops to deepen their understanding in a peripheral subject area. Other import practices and combinations of activities are well suited to the pursuit of learning. Colleagues, on an individual basis, can function as pointers, directing researchers to the most important and useful literature in outside subject areas. They work as quality filters, helping their contacts to find effective learning material. The process of collecting, filtering, and learning can also be performed by groups.

Team learning is practiced by some of the larger, more organized, research groups at the Center and within many other self-organizing research groups on the campus. In order to maintain active learning environments in their laboratories, some researchers have developed formal group methods for gathering and filtering literature within their laboratories. A neuroscience laboratory manager thinks of his lab members as a "roving information source"; they meet regularly to share new discoveries in the literature. A photosynthesis lab manager organized what he calls a journal club. Each student is responsible for scanning a set of journals in an area of interest to the lab members and then reporting back to the group. Once a month, they get together and each person presents the most interesting studies from their assigned titles. After using this technique for four years, the manager has decided to add another layer of filtering to the process by having the Center's library provide article titles and abstracts based on keywords selected by the group. The group meets on a regular basis to teach each other what they have learned through their exploration of the literature.

Frequently, the next stage in this process is footnote chasing.[25] Once a group member identifies an important paper for learning about a new area, they follow the channels of references through the literature. This is a standard practice for researchers and scholars in most fields, but because of the dispersion problem in cross-disciplinary work, this technique may be the best or only way of identifying pertinent material in peripheral bodies of literature. Name-based searching is a related technique. Many researchers watch for, or search out, papers by the people they respect or recognize in a problem area. The photosynthesis specialist acknowledged the limitations of the name recognition strategy:[26]

> "If Joe Block published a paper and you know Joe is a bright guy, then it is going to have something interesting to say. Where if Bill Scum publishes a paper, you can be pretty sure that it will be the same old stuff, and you will waste your time reading it. Unfortunately, Bill Scum every now and then has a bright idea, and then no one reads it."

Joe Block has achieved a level of scientific authority that is accumulated by others when they choose to reference or build on his research.[27] It is possible that name recognition may not play as great a role in cross-disciplinary work, however, since an author's reputation is not always known by those in an outside field.

We have seen that colleagues in personal networks add context and meaning to new information, thereby helping to transform it into useful knowledge. Reading followed by discussion appears to be one of the most valuable information routines for research-related learning. This is the sequence of activities that is applied in the standard college seminar and in the photosynthesis specialist's journal club. This type of deliberate learning is also practiced informally in small groups and pairs. Two researchers from different fields, an experimentalist and a theoretician, combined reading and discussion in a dedicated interactive way for an extended period of time to learn the basics of biochemistry. They met regularly to discuss readings from a standard textbook. We "picked up a couple of new biochem books and met for lunch every Thursday for a year and ground our way through." A number of other researchers cited textbooks and other "basic" derivative works as good sources for learning in new subject areas.

Some accomplish the difficult task of new learning by attending workshops and classes. One psychologist attends a series of classes each summer in order to "retool" and to keep up with the "complex formal systems" in linguistics. A language modeler, who was collaborating with a lawyer, devoted a substantial amount of time one semester to learning more about the law:

> It must have been my sabbatical year, otherwise I would not have possibly had time to hang around the law school and go to an evidence class every day and do the readings for it. But I learned a lot doing it that way.

The quality of learning through course work and workshops is obviously very high, but few take advantage of formal teaching forums. Most learning is self or group sustained.[28]

The Center attempts to promote cross-disciplinary understanding through a general interest colloquia series. The director had been disappointed by the attendance, however.

> The idea is, I am a neuroscientist and I am going to listen to this guy from computational electronics tell me in layman's language what he does and why he finds it interesting, but the program never really worked very well. I mean, the people who came to the talks were largely the people who were in the disciplines from which the faculty member came. There was not very much crossing over.

More distinguished speakers drew a little better crowd but also fell short of fulfilling the cross-fertilization function that the director had hoped for. While the numbers attending these programs may not have been great, certain individuals considered them an important part of their research learning process. They seemed to be most stimulated by the presentations on topics that were very distant from their own field. The neurophysiologist gave a specific example of how his research benefited from a lecture that appeared to be in an unrelated research area:

> So this guy came and talked about his model of swarms, swarms of ants, the dynamics of swarms of insects, and how they can accomplish things. . . . I just thought it sounded interesting, and of course the guy who presented this also had the idea that this could be applicable. He didn't know where, but more broadly in a general way. When I went to the seminar, I thought it very interesting, and now recently we've been able to apply a model like that to learning in the nervous system, where learning is autonomous and cooperative. Where individual elements kind of search around randomly like ants, and when they do the right thing, then they persist at that; they cooperate.

Researchers attend lectures in outside fields hoping to learn something pivotal or experience a flash of insight. To them, discovering an exciting new idea or research direction is well worth the investment in time.

Even though the Center makes this kind of learning convenient by hosting a variety of lectures, most researchers felt they still did not have time to take advantage of the programs. Those who did not go to the presentations understood that they were missing something valuable and wished they could fit them into their routines. The researchers who emphasized the importance of these talks tended to be interested in concept and theory development and made learning a clear priority in their research work.

Collaboration offers a valuable working structure for project-focused learning. The collaborative projects described by the scientists varied in "range of connections" and in terms of integration. The director characterized integrative collaborations as "something that requires real doing back and forth on both sides." "Additive research," he explained, is "where it is just a cookie cutter sort of thing."

> One of the things that makes for a collaboration is where work has to be done at both ends. That is, the theory isn't ready made to solve this, to attack the data, and the experimental data at hand aren't precisely the data which the theoretician would ask for if he were going to test his theories.

This type of cooperative work, that spans broad domains and strives for integration, offers an excellent opportunity for knowledge base development:

> Where you have the least in common you learn the most because you are stretching yourself more. On the other hand, for productivity, you are far better off working with somebody you already can work with. . . . If there is one person way over there and another person here and they are trying to find common ground in the middle, well, sometimes it works and sometimes it doesn't. But in trying to get to that common ground, you are covering a lot more territory (complex systems chemist).

Strenuous collaborations that require extensive new learning and translation between disciplines progress gradually. Researchers described this type of work as challenging and frustrating, and it is clearly a strain on young scientists who must produce published results on a regular basis in order to advance their careers. Getting to the stage where a coherent cross-disciplinary proposal can be written is a significant achievement in itself.

Intermediaries

Compared to all the other types of boundary elements, people are the most vital. We have observed that they play a critical role by acting as nodes for information transfer in personal networks. They also perform another critical boundary-crossing function. Certain people serve as conduits, enhancing the exchange of information by learning, filtering, analyzing, and making intellectual connections for the scientists. They function as transfer mechanisms or intermediaries between scientific communities. An intermediary may bridge the work of two different labs, act as a carrier of knowledge between academic research and industry, or provide the link between experimentation and theory. Within the context of this study, this unique research function is most often allotted to graduate students.

For an applied computation project, a database specialist trained a graduate student to work as an emissary. The student went out into the private sector for an extended period of time to live in and learn about the needs of the community and to establish a solid connection for the future. Researchers also use students to gain knowledge from other academic camps. A structural biologist explained that "if we don't know a certain technique, we will send people to an expert's lab to learn how to do it." The photosynthesis specialist conducts a trading program between his and several colleagues' labs. The students cross the border and stay long enough to learn the practices of the other community and, when they return, they can apply the new knowledge to their own work and teach others in their own lab.

> Students from my lab work in Mac's lab, and Mac's students work in my lab. So my students learn molecular engineering, and some of Mac's students learn to do biophysical experiments. Through that I've got students and post docs who do biomolecular engineering in my lab as well.

One student's internship turned out to be particularly beneficial for both sides. When he came back to the home laboratory, he had the ability to set up a new molecular engineering facility. Shortly after doing so, he proceeded to invent an entirely new method. "It actually works better than the one used [in the other lab], and now they are using our new method in their lab."[29]

Frequently, information must be translated before it can be understood or applied. All the researchers seemed to be acutely aware of the communication difficulties across disciplinary boundaries, and a few recognized the need for intermediaries who can interpret and convey the basics about problems and approaches. The complex systems chemist is part of a project that is trying to span an extensive experimental/theoretical divide. He is responsible for the experiments, and his research partner, a physicist, is developing the theory. They have assigned a series of graduate students to translate and mediate between them on this very ambitious project. According to the chemist, the main problem is:

> It is not clear how to take [the physicist's] results and translate it into a computer file to send over to the computer to say turn these pumps on at thus and so time and run them at thus and so rate—this is what the output is supposed to be. We are now on our second physics graduate student trying to act as the lubricant to translate the two.

The student intermediary has the task of determining what can be maneuvered in the chemical world of one scientist and how it relates to the symbols in the other scientist's physical world. The chemist seemed to be confident that, with time and a lot of concentrated work, the students could succeed in functioning as translators. However, turnover is a complication. This project is a complex long-term undertaking, and before new graduate students can make a contribution, they need to get situated in the problem and learn the specifics of the study.[30] After the intermediary develops the translation skills, it is not clear how much is transferred back to the chemist and the physicist and how much is lost when the student leaves the project.

Many of the research groups at the Center are applying the most sophisticated computer methods available to biology and physics. As a result, numerous students must bridge these domains as well, providing the intersection between modern computational technology and more traditional discipline-based sciences. Intermediating between the two involves blending experimental expertise with competence in current computer methodologies, each of which takes a tremendous commitment on the part of the student. An individual who comes from a rigorous physics background has to develop computer science expertise and learn biology. Those trained in computer science lack the physics and biology background. The demands of developing the combination of intellectual grounding and skills can be overwhelming, and several of the scientists talked about their programs as if the expectations they place on students are unrealistic. The theoretical physicist feels obligated to discourage some students:

> It's very hard and, actually, I have quite a number of people who do not finish. It is very tricky, and I am a very open person in telling my students that they may want to consider not getting their Ph.D. in this. . . . I tell a certain fraction at an early stage that they have little chance. Those who have stayed on with me actually all finished.

A protein specialist admitted that he was very tough on his students and that he expects them to be as diverse as him. A movement specialist, who has worked for the aerospace industry, government, and within universities, does not recommend interdisciplinary research for students who are planning to work within university structures. He believes it is unreasonable to expect people to follow a cross-disciplinary path within the confines of academe. He does not think, however, that interdisciplinary training is wasted on the students who want careers outside of the academy. Two of his recent graduates have found positions where the advantages of an interdisciplinary research orientation can be actualized. One is working at NASA and the other at General Motors—sites that are very problem oriented in their research aims.

The Import/Export Imbalance

There is a considerable difference in the amount of effort researchers put into importing and exporting information across boundaries. Import strategies, although not standard across cases, are practiced regularly by all the researchers. The scientists all rely on multidisciplinary personal networks and specialized conferences, and many integrate individual and group learning practices into their research processes and utilize intermediaries in their information work. Cross-disciplinary export—that is, the active delivery of information across boundaries—is much less common. Only a couple of researchers try to reach multiple audiences, and the few who have attempted to write for general audiences are not convinced that they have done so effectively. The researchers appreciate the "really good communicators," but their research practices do not necessarily include trying to be one. While researchers were highly aware of the language problems involved in importing across disciplines, only a few consciously use language differently for different audiences.

Overall, the lack of equilibrium between import and export appears to be an accepted condition of research. Even at the Center, where the exchange of information across boundaries is a high priority, increasing export is not stressed, except in terms of making information, as it currently exists, more accessible electronically. At the time of the interviews, a few of the research groups had made some information about their projects more widely available via the Internet, and the administration had started exploring ways of using electronic networks to increase visibility of the Center's activities.

In a study of cross-disciplinary research, it is easy to focus on cooperative approaches to science and neglect the competitive aspects of the enterprise. Cooperation is often necessary to complete a specific project, but within and between fields there is intense competition for resources, authority, and territory. Rivalry could be a factor in the differential between import and export. Aggressive import helps individuals advance their careers by enhancing problem solving and, in some cases, the practice may lead to important new discoveries. Aggressive export, on the other hand, enriches adjacent domains and could lead to the advancement or encroachment of another discipline.

According to the theoretical physicist, leading scientists have a "Darwinian urge to carry on their species."

> They recognize endangerment of their field early on, eliminating competing research fields by outgrowing them, stealing opportunity for growth in new areas by continuing growth in their own disciplines. Worse, scientists of established disciplines are the gatekeepers for hiring, tenure decisions, academic honors, and funding. In the Darwinian struggle of the disciplines, these scientists make use of their power. It would be malicious to state that this is done consciously. The scientists are deeply convinced that they do the best thing, but the outcome is disastrous for emerging disciplines.

The above theoretical physicist used a sporting metaphor to describe the competitive nature of science, comparing the defensive tactics of scientists to a tactic used in soccer:

> Basically, you kick very far away from the goal so there is no chance [for the other team]. . . . Scientists will kick it way over there (points in the other direction) if they know a guy has intentions to go here. . . . They realize that it might one day endanger the field they are defending.

Clearly, active export conflicts with the motives behind prechecking. Competition may continue to keep researchers from actively disseminating their findings and ideas into other domains, with import remaining the emphasis of their boundary-crossing information work. There is a clear opportunity here for information professionals to assist in the information transfer cycle by facilitating the dissemination of information across disciplinary boundaries. To do so, we will need to set our goals beyond providing access and begin concentrating on how to promote interaction and synthesis.

Shifting Emphasis to the Periphery

According to Chubin (1976), knowledge is centered around an intellectual core and, at the same time, overlaps in the periphery through "scatter." Compared to discipline-based inquiry, cross-disciplinary research puts more emphasis on information in the peripheral areas. The problem-centered research process accumulates peripheral knowledge and attempts to integrate it into the core knowledge unit.[31] Researchers' activities channel dispersed knowledge toward a specific problem, reconfiguring the core by reinforcing and initiating links to relevant peripheral areas. For many scientists at the Center, the core is already a mix of disciplines, a hybrid specialization (see Dogan in this issue of *Library Trends* and Dogan & Pahre, 1990). For example, the vision specialist considers computer vision his core research area, and the peripheral domains that he draws from are the less specialized areas of psychophysics, neurophysiology, and graphics.

Many researchers find that to play the science game strategically, they need to sustain a firm position in a discipline-based specialization while they target cross-disciplinary opportunities. Therefore, as the scientists explore new problems, many do not necessarily abandon their disciplinary concentrations. They maintain dual or multiple research focuses, continuing to build on their core area as they make the transition into a newer hybrid area. Core maintenance can keep a career intact and sustain funding while a researcher starts as a novice in a territory where he or she is not recognized. At the same time, boundary objects and accumulation strategies make it possible for researchers to capitalize on the periphery in order to create a broader and more powerful base for understanding and investigating scientific problems.[32]

Unplanned events and unexpected discoveries can also steer researchers into the periphery. The scientists were forthcoming about the role of serendipity, happenstance, and coincidence in science. A human factors psychologist compared science to dating: "It's like meeting someone in a bar—connections are often made by chance." Nevertheless, strategies are employed to increase the chances of serendipitous discovery. The researchers who practice undirected broad reading and attend talks that are far afield from their core are engineering situations where fortuitous discoveries might occur in the periphery. Through the process of experimentation, scientists may shift their investigation away from the initial focus. For example, a biophysicist accidentally disproved a hypothesis about how plants adapt to drought. During an experiment, he recognized that his data were inconsistent with his understanding of a certain biological system. He had enough grounding in a peripheral area to see that his data conflicted with his assumptions, and this discovery put him on a completely new research track.

FACILITATING BOUNDARY-CROSSING INFORMATION WORK

Having asserted from the outset of this article that information professionals are part of the research process, what can we do to advance the cause of interdisciplinary integration? The first step is to understand how information is used in the cross-disciplinary research process. Clearly, we need considerable work in this area (see Bates, 1996); however, with a baseline understanding of the research practices of successful interdisciplinary scientists, we can begin to formulate the types of information initiatives that may promote boundary-crossing inquiry. This study suggests that information environments for cross-disciplinary researchers should be conducive to probing and learning. Moreover, information systems need to include tools that function as boundary objects, and librarians need to be equipped to serve as boundary intermediaries, providing services that transfer and translate information across scientific communities.

Fortunately, recognizing and addressing the important role of faculty learning in cross-disciplinary research should enhance, rather than detract from, the pedagogical aspect of academic library services. Some of the information needs of boundary-crossing researchers parallel those of students who are developing backgrounds in new subjects. The researchers' reading practices show that multidisciplinary periodicals and general texts are central to maintaining a broad perspective. Collections that support learning need to include derivative works—such as textbooks, handbooks, and review literature—which are important counterparts to the masses of reports published in scholarly research journals. These more general works are studied and consulted frequently and would make good candidates for a working digital collection that can be shared by many and accessed remotely. Texts could be gathered based on the reading preferences of hybrid communities and centralized electronically around problem areas.

Integrative reviews of research (see Smith's article in this issue of *Library Trends*) written by experts provide syntheses of quality-filtered information. Reviews that bring together work from different disciplines are textual products that can serve as organizational outlines for consolidating disparate literature on developing interdisciplinary topics. Tools for discipline crossing can be created by digitizing these synthetic works and providing a link to the full text of each reference. The process of linking references to the source texts creates a web of information that spreads out from the problem, much like the process of footnote chasing, a common practice of researchers. The framework is reflective of the way knowledge connects, spreads, and grows. This type of boundary service can also help combat overload for, as one researcher indicated, compiling reviews saves "generation after generation from hitting their heads against the same problem." Since there are few incentives for scientists to take on bibliographic compilation projects, information professionals need to initiate collaborative arrangements with experts to produce high quality problem-centered information tools.

Exchange is the essence of cross-disciplinary work, and researchers rely on context and explanations in order to make meaningful, rather than superficial, use of material from outside subject areas. Information exchange systems need to be aligned with the types of interactions researchers find the most useful. We have observed the important role of undeveloped research, what the computational neuroscientist called results "with no deep ideas attached yet." Exposure to raw results allows scientists to think about a study in relation to their own research problems and methods before it is formulated into a paper that has been composed to fit the profile of a discipline-based journal or the preferences of an editorial board. This is why researchers find specialized conferences so worthwhile. They are a forum for discussing their work at an unrefined level—a place where they can talk shop on an enlarged multidisciplinary scale.

Research progress is dependent on many types of exchange. Perhaps we have been overly concerned with the question of how to control the quality of digital information, especially if in doing so we overlook the researchers' need for materials at different stages of development. As we dismantle the barriers among disciplines, we should also be working to build permeable boundaries among different types of information. Some progress has been made in networking data archives and making them available electronically.[33] Attention should also be given to making raw data and unprocessed results accessible in separate, yet linked, archives—side by side with refereed research articles. As we upgrade our libraries and information service organizations, it would be a mistake to continue to emphasize only the published product or the electronic equivalent. We will need to develop new standards and criteria for the presentation of raw data and results and create platforms for discussion around materials.

It may be true, as Pahre (1995 and his article in this issue of *Library Trends*) suggests, that actual communities do not organize around concepts. However, the neurophysiologist and other researchers in this study attach great value to the metaphorical application of concepts across scientific communities for communication purposes as well as for the development of theory. At present, there are few concept-based information tools.[34] Mapping concepts across disciplines can help us identify, and perhaps even predict, broader knowledge structures that are not bound by specialization or the existing scientific networks. In addition, tracing terms may provide some insights into how concepts cross borders and change meaning over time.[35] The vision specialist spoke of how the term "accommodation" migrated from studies of the human eye in psychophysics to ocular machines in artificial intelligence. Mapping of the concept could be taken much further to include the use of accommodation in linguistic theory, spatial orientations in architecture, and adaptation in biology. Likewise, it is possible that the complex system chemist, who studies oscillating systems, might benefit from knowing how oscillation is applied to the notion of noise in information theory.

While researchers are somewhat ambivalent about their audiences, they clearly benefit from intellectual comrades, and those who come from different backgrounds can make invaluable consultants and collaborators. For the scientists in this study, the Center is a place where a "stew of really disparate elements" has produced a functional pool of "creative and atypical people." Librarians can provide boundary services that foster similar intellectual associations by actively disseminating work across domains and helping to link scientists to others who have complementary expertise. Improved capabilities for searching multiple files and databases are needed,[36] but we must also increase our understanding of how concepts and terminology relate across user groups and information products. Moreover, current awareness programs that concentrate on literature in peripheral knowledge domains, instead of core research areas, may be considerably more beneficial to researchers and scholars with interdisciplinary interests.[37] After all, scientists are likely to need more assistance in areas where they have not had extensive training.

Cross-disciplinary researchers need to probe, retrieve, and learn within core and peripheral knowledge domains, and the borders between domains are mutable. Information environments should be flexible enough to accommodate changing boundaries. Undoubtedly, many users will continue to have a need for disciplinary approaches to information. Hypertext capabilities allow us to create adaptable systems that can place in the foreground either the periphery or the core, whichever framework is best suited to the researcher's problem area and approach. Unfortunately, as the World Wide Web develops, we often see disciplines differentiated first, and then there is an attempt to fit the innumerable fragments of information into these ill-suited categories. As we come to understand our clientele within problem-centered user groups and work toward comprehension of overarching conceptual territories,[38] we will gain a better understanding of potential organizing units. We can then become informed and active participants in the export process by making linguistic and electronic links that will promote freer exchange across boundaries, and by creating information tools that are configured around the actual research problems and information work practices of contemporary researchers. Information professionals who work to design systems and services that maintain open channels between scientific and scholarly communities will be taking on part of the information burden experienced by individual researchers, while enabling the ongoing boundary-crossing dialogue that is essential to the integration of knowledge.

NOTES

1 See Palmer (in press) on the need to organize information around problem areas.

2 Klein (in this issue of *Library Trends;* in press) presents a panoply of claims that knowledge is becoming more interdisciplinary. Twentieth-century assertions date back to the Social Science Research Council in the 1930s and the Manhattan Project. After a resurgence of interest in the 1960s and 1970s, the importance of interdisciplinary approaches is now widely acknowledged. As Klein (in press) points out, even *The New York Times* periodically heralds "new research developments under the banner of interdisciplinarity" (p. 13, unpublished manuscript).

3 T. D. Wilson (1981) defines the "user's life world" as the "totality of experiences centred upon the individual as an information user" (p. 6). He calls attention to the need to explore the role of information in the user's organizational and social settings, rather than studying information sources and systems.

4 See Bouazza (1989) for a review of previous user studies. He outlines the major studies on scientists, social scientists, and humanists. However, none of the works mentioned specifically address interdisciplinary researchers.

5 Citation studies are also done in other fields to define or describe the intellectual content of a discipline or specialty. See, for example, J. A. LaPonce's (1980) study in political science.

6 See, for example, Allen (1980), Choi (1988), Cronin and Davenport (1989), and Hurd (1992).

7 Kuhn (1970, 1977) and Ravetz (1971) were instrumental in directing attention to the practice of science. Other important works include Latour and Woolgar (1979) and Knorr-Cetina (1981). See Clarke and Fujimura (1992) for a comprehensive review of influential works on science as work.

8 See Pahre (1995, also in this issue of *Library Trends*) on how methods, data, results, and concepts influence the formation of intellectual communities.

9 In a recent review in *Science* of "yet another" festschrift honoring the life and work of Dobzhansky, Jerry A. Coyne (1995) comments on how "ancestor awareness" has become a form of "ancestor worship" in the field of evolutionary biology.

10 The term "problem-oriented research" was used by F. A. Long (1986) in his *Science* editorial on the need to support interdisciplinary research at universities. Klein (1990) uses "problem-focused research" to describe research teams working between the poles of pure theory and informed action. My use of "problem-centered" incorporates the various types of boundary-crossing that occur during problem solving, including movement into other disciplines and between theory, experimentation, and application. Problem-centered research has been practiced outside of academic contexts, in organizations such as NASA and Bell Laboratories, and is a common orientation for the research performed in industry and medicine.

11 Bruno Latour's (1987) definition of knowledge as a "cycle of accumulation" incorporates the many dimensions of knowledge development. He explains that "knowledge cannot be defined without understanding what *gaining* knowledge means....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 (p. 220).

12 The importance of both formal and informal communication has been explored in various scientific contexts. For example, as part of the important APA Project on Scientific Information Exchange, Garvey and Griffith (1964) found that literature and conversations with colleagues are emphasized in different stages of the research process.

13 Management research has shown that, when there is high uncertainty in a situation, an individual is likely to prefer oral over written communication (O'Reilly, 1982).

14 While Cronin (1982) does not specifically talk about integration, he notes that informal communication "facilitate(s) boundary spanning, i.e., helps transmit ideas across disciplines." He summarizes other advantages as follows: increases match between information needs and delivery; encourages feedback and increases motivation; helps establish priority in discovery; allows reality-testing; current awareness; allows researchers to screen information; and bonding effect on groups (p. 224).

15 Sproull and Kiesler (1991) document similar advantages of electronic communication for group coordination in organizational work.

16 There is evidence that only 18 percent of all conferences are meetings of large societies. The majority are being organized around specific problems or topics (Oseman, 1989, p. 3).

17 Star Trek: Deep Space Nine is a science fiction television series about a remote space station at the edge of a new frontier in outer space. "Travelers of all kinds are drawn here, and with hostile alien empires bordering every side, Deep Space Nine becomes the most strategic point in the galaxy" (description from a Paramount Television Current Productions home page, November 1995).

18 This search for the "undercurrent" by cross-disciplinary researchers is done through formal and informal means. The researchers in this study found both channels important; however, the 1963 APA studies indicated that 80-90 percent of useful information at conferences was gained by attending formal presentations and events. Paisley and Parker (1967) report comparable results. Compton (1966) may have tapped the "undercurrent" advantage of conference information when she found that attendees receive a substantial amount of useful, but "unsought," information.

19 See Wilson (in this issue of *Library Trends*) and Weick (1970) for in-depth discussions of information overload.

20 In their survey on the impact of electronic networks on scholarly communication, McClure et al. (1991) also found that researchers commented most about the ability of networks to enhance interaction between colleagues. Based on my follow-up interviews, less than two years after the initial data were collected for this study, it appears that many of the researchers are beginning to incorporate the Internet into their information practices.

21 There are many definitions of browsing in the library and information science literature. Here I have adopted Chang and Rice's (1993) notion of browsing as searching that can be goal directed or nongoal directed and unplanned.

22 The percentages are almost the same for the subset of researchers selected for this study—40 percent and 60 percent respectively. This level of use seems somewhat higher than in other studies of scientists. Hiltz (1984) determined that 30 percent of her respondents found the Electronic Information Exchange System "extremely valuable" for retrieval and searches. McClure et al. (1991) found that functions such as online database searching and remote data sources are used infrequently relative to e-mail, file transfer, and other computer resources.

23 In a 1973 study of physical scientists, Skelton (1973) found otherwise. Review literature was not considered to be especially useful. I would speculate that the interdisciplinarity of the researchers in this study accounts for the difference in attitude. These researchers are specifically seeking sources that will function as boundary objects.

24 See Palmer (1996; in press) for a discussion of the knowledge levels required for interdisciplinary work.

25 In the *Handbook of Research Synthesis* (1994), White refers to footnote chasing as "scholarly intelligence" (p. 46). The practice provides evaluated and highly conditional references compared to the listings of subject-based bibliographies.

26 Name searching, like footnote chasing and consultation, can introduce bias because it is selective and tends to be homogeneous. See Cooper (1989) for a discussion of the limits of invisible colleges as reference groups for integrative research.

27 Bourdieu (1975) analyzes scientific authority as a kind of "social capital," the value of which is reflected in reputation, prestige, and authority. There is, however, "no arbitrating

authority" that can legitimate authorities: "there are no good judges, because there is no judge who is not also a party to the dispute" (pp. 23-25). Kenneth Boulding (1968) also provides an economic analysis of scientific knowledge, while recognizing the important role of librarians as "specialized intellectual middlemen" in the exchange of intellectual capital.

[28] Klein (in press) identifies faculty learning communities as important contributors to interdisciplinary knowledge production.

[29] In his study of the U. S. steel industry, Eric von Hippel (1988) links innovation to informal "know-how" trading that takes place between companies. He demonstrates that even rival firms exchange specialized knowledge within networks of engineers with common research interests.

[30] See Lave and Wenger (1991) for a theoretical development of situated learning, the process by which a person is transformed from a "newcomer" to an "old-timer" and becomes a member of a community of practice.

[31] Fisher's (1990) notion of a knowledge core is aligned with cross-disciplinary inquiry; he describes the core itself as an integration of domains. Subjects within the core may be specialized and fragmented, but they exist in open relation to each other, equal in emphasis and interdependent. Subjects outside the core are less integrated units of knowledge.

[32] See Palmer (1996) on how work conditions influence individual levels of core and periphery and how abundant resources, rewards, sense of community, validation, and technological capability provide the leeway that accommodates ventures into the periphery.

[33] This is especially true in the social sciences, where data resources such as the Inter-university Consortium for Political and Social Research, The Roper Center, and various university-based archives are beginning to provide World Wide Web access.

[34] Progress has been slow in this area. Broad cross-disciplinary and conceptual classifications are beginning to appear on Internet gateway indexes and are becoming more common as access points to online databases and print bibliographic resources.

[35] In their work on automatic thesaurus generation, Chen et al. (1995) propose "time-tagging" concepts to increase precision and to address the problem of vocabulary fluidity in scientific domains over time.

[36] Dialindex on Dialog begins to address this problem, although the file groupings offered reinforce traditional disciplinary delineation. Very large multidisciplinary databases, like the Institute for Scientific Information's (ISI) citation indexes, are available but have limitations for searching subjects across disciplines.

[37] Bates (in this issue of *Library Trends*) provides a review of studies on information use in high and low scatter fields.

[38] Pahre's (1995 and in this issue of *Library Trends*) construct of metaphorical communities may prove useful for understanding and defining these territories.

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