To appear in *Cognitive Studies of Interdisciplinary Collaboration*

Making Interdisciplinary Collaboration Work

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Introduction

Cognitive science is, by definition, an *interdisciplinary* endeavor, one where the investigators have their formal training in different academic disciplines. This chapter is an informal study of how 21 people enjoy and succeed at it with researchers from other disciplines. It is based upon interviews and discussions with computer scientists and neuroscientists, psychologist and linguists, even a philosopher or two. Each of them is, by the standards of publication and research funding, a successful and expert interdisciplinary collaborator.

This report is anecdotal; it summarizes hours of conversation and pages of electronic mail, interspersed with some personal experience. Wherever possible, quotations appear, to let the respondents speak in their own experienced and authoritative voices. At their request, these are unattributed. A full list of the participants appears at the end of this chapter. Many of them generously volunteered details of failures, as well as successes, from their own experience at interdisciplinary collaboration.

In this chapter, *collaboration* is assumed to be joint work among two or more researchers of similar status (Thagard 1997). Collaboration is not just reading and writing about the other person's work. As one respondent said, "That's working in parallel." Nor is it collaboration when one person asks all the questions, and the other provides all the answers. The same person noted, "That's getting help." Collaboration often entails a degree of role play, where the participants alternate as learner and instructor.

Although this chapter is focused upon the particular features of *interdisciplinary* collaboration, where the investigators have their formal training in different disciplines, there are, of course, ingredients essential to any good collaboration. An obvious, but non-trivial one is willingness to work with other people. As one scientists ruefully observed, "Some people just don't like to collaborate." Arrogance or vanity on the part of any participant makes collaboration very difficult. Healthy mutual respect and good will are also important. A successful collaborator pointed out, "You [need to] consider each other equals." Because disagreements, over authorship and funding, as well as more intellectual matters, are inevitable "you need confidence in yourself and respect for the others." One scientist found that taking a long range view is helpful: "You need to believe that there will be results beyond a single paper." And, of course, fundamental human relationship skills are essential. Another researcher suggested, "Tell [your readers] to be nice … don't compete…have a healthy respect for each other." Stability in one's work and personal life is also important; several tales of failure emphasized how difficult collaboration became when people changed affiliations or became parents, particularly for the first time. Successful collaborators are volunteers; collaboration imposed upon its participants by an institution or funding agency is unlikely to succeed.

Certainly, there is a remarkable amount of interdisciplinary work out there. Examples in this study included:

- A psycholinguist and a computer scientist working in a computer science lab on the rapid detection of eye movement in natural settings.
- A team of pediatric neurologists, developmental neurobiologists, psychologists, and psycholinguists studying early childhood language development.
- Philosophical logicians and computer scientists formulating an ontology for geography, complete with a web site for ontology engineering in a philosophy department.

- A computer scientist and some psycholinguists shaping theoretical models to correlate with results on humans.

Researchers cite three primary motivations for interdisciplinary collaboration. First, the topic may demand it. As one scholar observed, "My area is inherently interdisciplinary … we need a confluence since no one discipline has a sufficiently rich language or a sufficiently rich perspective, let alone an answer [to these questions]." Another noted, "My area by definition requires broad-based knowledge for success anyway … by necessity you must reach out." The second common motivation for interdisciplinary collaboration is that it can provide a new perspective. One scientist asked, "Why get caught up in a single approach of your discipline?" Another said, "It's stimulating and thought provoking … it gives me access to other techniques." The third motivation is that interdisciplinary collaboration provides additional knowledge. One person wrote, "I always was very goal-oriented and felt that if I wanted to try to study a particular topic that spanned more than one discipline, why should I reinvent the wheel when I can work with people who specialize in that area I want to include in my study?" Another said that he turned to people in other disciplines because "they had tools and skills I needed." Still another recalled, "I had been doing a lot of experimental work which focused on various phenomena in isolation, and was beginning to feel frustrated by the lack of a coherent underlying account of the various fragments." Pragmatism is indeed a driving factor. As one researcher put it, quite matter of factly, "…they had skills I wanted to learn in order to answer some questions I was interested in…."

The remainder of this chapter focuses on the keys to a good interdisciplinary collaboration, recounts some stories, and offers advice for those about to embark upon it.

Key Elements

The key elements to a successful interdisciplinary collaboration are attitude, communication, time, proximity, institutional climate, funding, roles, appropriate topics, and publication. We consider them one at a time.

Attitude

The successful interdisciplinary collaborator is, of course, a good collaborator in the ways described above. The researchers should like each other. As one observed, "[It helps when you get along well because] you have so much else to surmount." They should also have complementary talents and expertise. One long term collaborator, in reflection, said, "We agreed a lot to begin with … [but] both believed the other had valuable things to communicate." Another observed, "You have to feel like it adds to both your work."

As a result, successful interdisciplinary collaborators appear to impose limits on the exchange of knowledge. One researcher asked, "It's too hard to learn that too -- why should a psychologist learn to code a simulation?" Another insisted, "… becoming an expert in each other's empirical techniques requires too many resources." It does help, however, if you share a theoretical framework and can use different empirical techniques. A scientist noted that "Wrapping your head around each other's theoretical perspective is essential." Nonetheless, some knowledge of other domains is useful. One respondent found interdisciplinary collaboration natural because "… I'm enough of a dilettante …."

A good interdisciplinary collaborator is, first and foremost, receptive. One particularly prolific collaborator said, "Everybody who has touched my work has made it better." In addition, however, one must have a good reason to work outside one's disciplinary rules. As a thoughtful respondent observed, "… My thinking style is basically analogical … I like to look for convergent evidence … It's easier for me to look for themes than to concentrate on detail …."

Clearly, a collaborator must be open to different disciplines. A senior researcher suggested that "Security in your own work helps you open up to new ideas." Another said, "[It helps when] researchers take an interest in big questions." Several people indicated that their early experience with interdisciplinary work, as a graduate student or a post-doctoral researcher, had particular influence. One person had to form his own interdisciplinary thesis committee; another was a psychologist with a civil engineer on

her committee. The collaborator may also need to be resourceful about locating colleagues. Several stories hinged on recognizing a need for an individual to do a particular task and then "find[ing] someone you know to do it … [you have to choose a person] you like and trust… someone who works hard and has a similar working style." (That last requirement, however, seems to be the one most often compromised.)

Once a team is formed, it is essential to know or learn about each collaborator's field. Recounting one collaboration, a respondent indicated that startup was relatively easy because "I already knew a fair amount of linguistics anyway." Efforts to learn are recognized, and appreciated. A scientist observed of another, with great admiration, "[she] would go miles to learn." Many an interdisciplinary collaboration succeeds or fails based on the ability to bow to each other's expertise. Respondents said how important it was to view interdisciplinary collaboration as a partnership, not as the exploitation of someone's useful technical skills. One insisted that, if it is to last, "You have to feel you are both doing something new."

People often engage in several interdisciplinary collaborations "because you have lots of ideas." Some are enduring; others produce a single paper after a year or two, and cease. Three of my respondents had extensive interdisciplinary collaborations with their spouses, as well as with others. Most agreed that "marriage" was an apt metaphor for an interdisciplinary endeavor. One person suggested that, like marriage, an interdisciplinary collaboration "start[s] off tentative, careful" and that you gradually "build up shared agreements and ways to get out of shared disagreements." A sense of humor was frequently cited as essential. Collaborations were described with warmth: "it was fun," "we were really having a good time … humor diffuses things," and "we kidded around a lot … a good mix of having fun and working hard … there's really got to be joy in it."

Communication

Even with the right attitude, however, interdisciplinary collaboration requires careful attention to language. Despite several years of work together, one participant noted, "…

[we] don't always understand each other the first time.…" A psychologist speaking with biologists and computer scientists about neural networks confronted what he termed "field-specific dialects. Thus although we're discussing a problem that may be relevant to cognitive science, our 'classic' training in specific disciplines makes it difficult to 'connect' appropriately." His computer scientist colleague reported a similar difficulty when she spoke with another psychologist. Fundamental terminology should be established early and reviewed regularly. This may mean that the minority chooses to speak the majority tongue. A computer scientist, for example, working with physiologists said, "I [learned and then] used their language to communicate." Alternatively, a common vocabulary can be deliberately constructed. A member of a group of collaborators reported: "We developed a third language [neither computer science nor neuroscience] that we could all use. [We] chose some known terms and then deliberately coined others that captured the ideas we were trying to address."

Discipline-specific jargon is easily acquired; it is the undetected, specialized use of the same words that creates real problems. For the first two or three years of our work together, every time we sat down to talk, one of my own collaborators extracted from his shirt pocket a 3 ∞ 5 card with a list of words and definitions supposedly in both our vocabularies, but ones that I defined in ways quite different from the way he would. "There," he would say, slapping the card on the table and scanning its contents, "that's Susan speak. Now we can talk." I attribute a great deal of our success together to that deliberate effort on his part. In contrast, one respondent spoke about what was, for him, a rare failure: "I thought we were talking the same language … we had great conversations in the cafeteria … it took me six months before I realized that [we were speaking different languages]." Another reported in frustration: "We had a real honeymoon for 6 months until we discovered that we had been using the most basic terms, such as 'symbol' with entirely different meanings." Other words that arose in similar stories were "representation," "schema," and "grammar."

Early vigilance is well repaid. Long-standing collaborators report no consciousness of any language problem whatsoever. They have formulated a common context. As one member of a pair said, "…we have such a bandwidth together … we share most of our models with each other … [there is] no need to rebuild [a shared] structure." My own recounted collaboration remains alive and well, but I have not seen that 3 ∞ 5 card in some time.

Time

Given the right attitude and accurate communication, time becomes an issue. Particularly in the first few years, interdisciplinary collaborations "take more time [than those within discipline]… which I don't mind because I enjoy them more". There is learning to be done, and a vocabulary to be established. One researcher said it was important to have students and collaborators present to each other regularly, another time-consuming activity. Even after the initial period, interdisciplinary work seems to be slower. One book authored by a group took, by one estimate, "three times as long to write [as it would have had I done it myself, and yet it was] a very positive experience." One respondent told of an interesting collaboration that he refused because of its fast-approaching deadline.

Academic obligations often make time allocation a real issue. One scientist, while happily cataloguing his many fruitful collaborations, repeatedly pointed out how much more freedom he had than his academic collaborators because his work situation does not depend on teaching responsibilities. In another collaboration there were "great connections" still influencing [the collaborators'] work, but the group never published because a key member was too busy. That cost them their funding, and ended the collaboration. Even one overextended collaborator can create serious problems.

Proximity

Once a well-motivated, clearly communicating team makes time to work together, proximity is important. One researcher defined *face time* as time collaborators spend in

the same room for the sole purpose of their mutual goals. During face time, he said, "You have their attention." Another observed, "You know, there really is no substitute for two hours of talk." Telephone conversations, in contrast, permit distractions. One respondent asked, "Did you ever hear someone typing at a keyboard while you spoke to them?" During face time, such behavior would be considered rude. And even during face time, care must be taken to control many potential office distractions: the telephone, alerts about new e-mail messages, students and colleagues who stop by to visit. Homes present special distractions of their own. One group of collaborators met in the evening always at the home of the only member in the group without children. In another collaboration between spouses, meetings were deliberately scheduled outside their home, and often included a meal.

Face time provides more than undivided attention. It is motivational, because it puts social pressure on each person, and leads to insights unavailable otherwise. Work that entails diagrams, vision, or spatial reasoning is particularly reliant on face time because drawing is intrinsic to communication.

Face time is particularly essential at the beginning of a collaboration. It enables you to learn the intonation and social aspects implicit in your communication early. Later, when your communication becomes primarily electronic, you can correctly interpret the nuances you learned during that initial contact. Many long-term interdisciplinary collaborations start out with a regular weekly meeting (an hour, or an evening) dedicated to the purpose of mutual education, with the hope that appropriate topics will eventually surface. Although one respondent insisted that a 20-year, very fruitful collaboration had always been long-distance, under repeated questioning she eventually recalled quite a different start. Although they had been acquainted for some time, only later, when she was on sabbatical at her collaborator's institution did they have six months of face time in which to brainstorm. Since then, their work has entailed "regular annual meetings, which lasted varying periods of time."

Face time not only begins an interdisciplinary collaboration, it keeps it alive. It should come as no surprise, then, that such collaboration is easier within a small geographical area. Visiting is expensive, time consuming, and stressful, typically involving hotel stays, extended child care, and air travel. One scholar recalled better days for a collaboration in which she had been involved for several years: "[two of us] had offices next to each other … We talked about the research almost every day, we were [there to] answer questions, bounce ideas off of.… Once I left … there was a definite decrease in the amount of work that [got] done on this project and also the clarity of the research question. Having [the third collaborator 500 miles away] wasn't really a problem, we used e-mail to tell him how things were going, but it was definitely better to have at least two of the 3 collaborators in the same building. I'm not saying it's impossible to work across institutions, but this leads to the other main factor: money."

Funding

Interdisciplinary collaboration tends to be expensive. Indeed most respondents identified funding as their greatest problem in interdisciplinary research. One person noted, "No outside funding slows you down." Another acknowledged, "It is important to be able to pay your collaborator." Interdisciplinary collaboration often requires the services of programmers, who are in great demand and command high salaries. One psychologist wrote, "the stimulus I use … tends to be more complicated … and I … do not know how to program, so I need money to hire someone [or] the stimulus doesn't get developed." That required proximity is expensive too. Indeed, an experienced collaborator characterized a "good visit" as one that lasted two weeks to three months and required a comfortable place to stay, a kitchen, a rental car, and copy and telephone privileges.

Many collaborators said that it was far easier to secure funding for their own work within discipline than for interdisciplinary proposals. There were a few noteworthy exceptions. Linguists and computer scientists readily find support, presumably because natural language processing is a well-established subfield of artificial intelligence. One

scientist, much of whose work was "industrial-related," had several collaborators who had moved to industry, from which they could, and did, readily offer support. A larger team credited its success in part to its early development under the aegis of the MacArthur Foundation, a farsighted supporter of long term, interdisciplinary research in the cognitive and behavioral sciences. Indeed, once funding is secured, interdisciplinary collaboration begins in earnest. Several people recounted stories where preliminary investigations blossomed into 10 to 20 papers after funding.

Regrettably, the review process for interdisciplinary work appears to be particularly problematic. One respondent noted that, "In [our country] now they claim to want to fund interdisciplinary work, but a proposal goes to a panel in a single discipline, so it is necessary to subordinate the work of all to the work of one …." If a review panel is constructed from experts in the individual disciplines, their disciplinary expertise may not be relevant, for example, the "wrong" branch of psychology. One researcher suggested that expertise in one of the fields involved in the proposal is not sufficient, that each reviewer should also have had experience as an interdisciplinary collaborator. Another told of a review panel that took the proposal's description of a successful prototype experiment as evidence that the group had already learned how to collaborate, and therefore did not require funding.

Institutional Climate

Interdisciplinary collaboration is particularly influenced by its environment. Institutions can deliberately become "homes for people who work across the traditional boundaries, and also people who, while rooted in a discipline, need support to spend time on stuff that isn't recognized by their discipline…." This approach is often termed *horizontal,* because it encourages people to organize themselves around a problem, rather than around a discipline or subdiscipline. In one deliberately interdisciplinary environment, newcomers must offer a three-month tutorial on their fields, and there is a weekly internal afternoon symposium and an annual four-day retreat to discuss mutual goals.

Since, as we have observed, interdisciplinary work takes more time, researchers involved in it must be relieved of other duties. Not surprisingly, many interdisciplinary collaborators teach at universities that reduce the course loads of active scholars. Supportive departments readily sponsor a collaborator as a research scientist, encourage visits, and invite talks from "neighboring" disciplines. Supportive communities are described as having a "multi-methodological tradition." Regrettably, the relative scarcity of cognitive science programs and departments in universities suggests that a narrow perspective remains all too common.

Since physical proximity fosters interdisciplinary work, researchers in companionable disciplines should also be near each other. One respondent observed an environmental irony: that "at small colleges you're more likely to share a building with philosophers and linguists and develop across discipline collaborations, but being at a small college there is less institutional support and more teaching and community service responsibilities."

In a large institution, physical proximity can be dictated to deliberately foster interdisciplinary work. For example, at AT&T's famed Murray Hill laboratory scientists of the same discipline were deliberately scattered in offices throughout the complex. A typical hallway housed a mathematician next to a chemist next to a physicist. Geographically, these were "people accustomed to playing in each others' backyards." The single, attractive dining room served excellent, inexpensive meals; all its tables were round and readily seated eight to ten people. The laboratory itself was relatively isolated, with few outside mealtime alternatives. Not surprisingly, lunch time conversation was wide-ranging, fertile ground for future collaboration.

Another institution that deliberately nurtures interdisciplinary research is the Center for the Study of Language and Information, an interinstitutional laboratory housed at Stanford University. One scholar notes that, "One crucial thing … is the building itself. It is almost impossible to around in it without meeting people having a discussion about something. The 'meeting places' are at corners of the corridors, so that informal, and

even sometimes formal, meetings have people wandering past all the time." Respondents cited examples of other places where interdisciplinary collaboration prospers: the University of California at San Diego, the Beckman Institute for Advanced Science and Technology at the University of Illinois, the Santa Fe Institute, and the Institute for the Interdisciplinary Study of Human & Machine Cognition at the University of West Florida.

Institutions that successfully foster interdisciplinary research address "the importance of non-intellectual factors … [that can] provide means to flourish … [and encourage] social bonding." One research facility takes care to begin everyone's contract on the same calendar day, so that no newcomer has more seniority than any other. The same institution mandates attendance at 4 o'clock tea and coffee every afternoon, with cake provided by the author of any newly accepted or newly published paper. Thus the researchers celebrate each other's achievements, and are encouraged to collaborate on new ones.

The Canadian Institute for Advanced Research (CIAR) ran a program from 1985 to 1995 to encourage interdisciplinary research among about 15 top university researchers in a variety of disciplines. To give these scholars the requisite additional time, CIAR released them from all obligations except one graduate-level course per year. To provide face time, CIAR required them all to attend an annual three-day meeting. At this meeting, and at the three-day workshops for subgroups, "increasing levels of sophistication [in each others' disciplines] were encouraged" because participants were expected to present their work to each other. Many of the scholars found this a supportive experience.

Roles and Learning

Most collaborators report that their work is facilitated by allocating responsibilities. This "useful division of labor" maintains progress (Thagard 1997). The respondents believed that collaborations required a leader to define the common problem and the language in which to discuss it, to set priorities, even to target publications. In small teams, they

report, the leadership assignment may alternate, and it is important to recognize your role in a particular situation. One respondent, however, insisted that consensus could govern instead, substituting patience and listening skills for a single leader. The impressive history of that group is ample support for this alternative model.

A second important role identified by many respondents was that of the *facilitator*. This person frequently translates the language of each collaborator for that of the others, and must be trusted by everyone. As a rule, the facilitator is not the leader, and is often a graduate student. One respondent describes this as "… a young, enthusiastic, intelligent person … learning from a linguist and a psychologist and a computer scientist, and asks questions to each from the other other's perspective, noticing links (and mismatches between usages and assumptions) that the teachers themselves would not otherwise discover." As another scholar indicated, "Either one of you develops mastery in the other's field, or one of you has a very smart student that does." For some very busy, senior researchers, such a student is essential for peer collaboration "because [otherwise] I'm too busy." In other peer collaborations, one discipline appears intermediate between others, and its representative serves as the facilitator.

Even with a facilitator and a leader, learning is essential and "…it's harder than you think [it is going to be." As one researcher reported, "… despite a great deal in common, we found that there were … large areas where the differences in background meant that a great deal of mutual education was necessary."

Appropriate Topics and Publication

Given the right individuals, good communication, a supportive environment, and plenty of time and money, interdisciplinary collaboration still requires a topic. "Some topics just beg for collaboration …." A good interdisciplinary topic is couched in several disciplines, none of which is particularly advanced toward a solution. It is also a problem of mutual interest. One successful collaborator recounted several different startup attempts that failed. In each case he had met regularly to "brainstorm with the explicit intention of

collaborating, but … [we] couldn't find an issue that grabbed both of us equally." Such complementarity is important. One successful collaboration began because, one scientist said, "Each of us felt we had half the answer." A good topic often demands new methods, costly facilities, or subjects available to only one of the collaborators. As one scholar indicated, "… collaboration will let me solve problems I could not solve on my own … because I lack tools that I see as relevant …." Several people suggested that applied research was likely to be interdisciplinary.

As work is accomplished, one individual reported that "The major stumbling blocks … have to do with who takes responsibility for writing the work up, where is it submitted, and who gets identified with the work." Typically, one person drafts the paper according to its targeted venue, and is therefore the first author. (One team, however, chose always to publish alphabetically, to avoid "silly wrangles.") The drafter typically assigns sections to the others, or leaves "holes" for a collaborator to fill in with data, elaboration, or scholarly support from the other's discipline. The first author also becomes identified with the work in the discipline where the publication appears. Very strong results double the places available to publish. For smaller interdisciplinary results, however, finding a venue is likely to be much more difficult.

Case Histories

This section chronicles some scenarios in interdisciplinary collaboration. John-Steiner describes four patterns of collaboration: distributed, complementary, family, and integrative (John-Steiner 1998). the respondents provided many examples of each type; their assignment to categories is my own.

A distributed collaboration

Distributed collaborations are "characterized by informal, voluntary roles, similar interests, and spontaneous and responsive working methods" (John-Steiner 1998). Participants in a distributed collaboration "exchange information and explore thoughts and opinions" (John-Steiner 1998). One philosopher respondent told of a model he had

promulgated in a paper at an annual meeting of the Cognitive Science Society. A psychologist disagreed with the model, and they ultimately collaborated in a series of computer-based simulations and experiments on people. Their results refuted the original model and appeared in a paper at a subsequent meeting of the same society. With the resolution of the issue, the collaboration ended, leaving both participants more knowledgeable.

A complementary collaboration

Complementary collaborations form the bulk of the work described here; the researchers partition the work according to their skills, knowledge, and temperaments. Individual strengths are combined to develop and disseminate a body of work. These strengths include mathematical skill, well-equipped laboratories, organizational talent, writing ability, and a network of colleagues. Participants in a complementary collaboration bring pieces of the same puzzle to the table. One respondent, a linguist by training, wrote, "I had been doing a lot of experimental work which focused on various phenomena is isolation, and was beginning to feel frustrated by the lack of a coherent underlying account of the various fragments … So I began to hang out at [psychology] lab meetings [in my own university], and then began what turned into a long-term collaboration with [a psychologist]. Whereas I had a solid background in the domain of speech perception, but little experience developing behaviorally-oriented computational models, [he] knew more about modeling but little about speech perception." The result was a set of ground-breaking papers.

A second example of a complementary collaboration occurred among a group of four scholars: a cognitive psychologist, a social psychologist, a computer scientist, and a philosopher. Initially they met weekly for a year, educating each other and establishing good communication. At the end of that year, they decided to write a book together. After the group outlined the project, one person was assigned to draft each chapter, but revision was thorough. One of the authors wonders, "Who knows if there were even sentences of

the first chapter that wound up in the book…?" One of the chapters had at least 20 versions. Nonetheless, he believes that the resulting book was only possible as a group project; "no one [of us] could have done it alone."

Several years later, two of those four authors wrote a second book together. This time it was "much easier … [because] we had a common theoretical framework to start." They met only once in 18 months of writing, at a dinner to work on one problematic chapter. "Neither of us knew much about [it] so we each wrote a draft and then merged them — I think it's the most fun chapter in the book."

A family collaboration

In *family collaborations*, people interchange roles more often and share a common expertise. One remarkable example of a family collaboration is a developmental research center begun with long-term funding from the MacArthur Foundation and perpetuated through grants from the National Institute of Health. Fourteen researchers from psychology, pediatric neurology, and developmental neurobiology have collaborated within it for more than 10 years. The team works collectively, always seeking consensus in their weekly meetings, even on budgetary matters. They organize their efforts horizontally, along questions rather than disciplines. Their communication, after so many years, is effortless, and their publication record exemplary.

An integrative collaboration

John-Steiner believes that the epitome of collaboration is *integrative*, an intense, long-term relationship in which people share a vision, draft together, and ultimately construct "a new mode of thought." Collaborators in such relationships no longer distinguish substantial segments of ideas or results as the property of a single individual. The production of a recent book is an example of integrative collaboration, where a team of six authors forged a new perspective together. The group consisted of two psychologists, a developmental neuroscientist, a psycholinguist, a computational linguist, and a cognitive scientist. Each member had worked with at least one of the others previously,

and had participated in a training program that involved both post-doctoral students and senior scientists. At the close of the training program, they decided to write a book.

As one of the authors recounts, "Initially, we envisioned an edited book with each author contributing one or more chapters. But in our early planning sessions we discovered that there were some deep issues that needed discussion first. So we began what turned into a three-year informal proseminar." The collaborators were spread around the world, but they met once or twice a year. "…we secluded ourselves and met intensively for six to eight hours a day, for five to 10 days. … The process was hard because, despite a great deal in common, we found that there were significant points of disagreement." Although they began as, and remained, good friends, frustrations arose. One participant recalls some theoretical disagreements so severe that people wanted to pull out, but the "solid commitment to the importance of what we were doing" held them together.

Eventually, the six had a joint outline that described the contents of each chapter. Then, in contrast to the book collaborations described above, every author wrote a working paper for every chapter. One author notes, "I had a two-foot pile of stuff." After each person had read all the drafts, teams of two or three drafted each chapter. Everyone worked on at least five chapters, sharing a computer or writing fragments. One chapter in particular went through four full versions over 18 months. Finally, one person took the responsibility for unifying the text and style. His final verdict: "The outcome [after four years] … was deeply satisfying. All of us felt changed by the process. … [It] was clearly something that none of us could have written alone."

Some Concluding Advice

Crossing disciplines is fraught with peril. In some sense, a discipline forms one's outlook. As one respondent put it, "A disciplinary affiliation is more than just a body of knowledge and expertise: it's also a set of cultural attitudes." Since a discipline defines what is expected of and valued in a professional, it may reject what is foreign on those

terms. We are often narrowed in our education and narrowed once again as we become experts in our field. By definition, interdisciplinary collaboration contends that there is more than one way to address a problem. Therefore one must be willing to step outside one's culture and training, to consider other approaches once again.

A good example of this challenge to one's perspective is the development of a course on computational models of learning, team taught in one school by a psychologist, a biologist, and two computer scientists. At a meeting to formulate the syllabus, the psychologist relates, "We had a hard time agreeing on the appropriate way to structure the course: The biologist wanted to spend the first third of the course on the nature of brain and neuron structure, the CS people wanted to do basic computation, [and] I wanted to establish the relevance to modeling human behavior…." The integration of ideas from different disciplines is non-trivial; it requires open and creative minds.

Make certain that the intellectual community is receptive to your intended work. Not only must the individuals be ready to collaborate, but the disciplines must be amenable as well. Several respondents told stories of disciplinary arrogance, particularly of professionals in other areas who viewed computer scientists merely as support personnel, "just another techy." Even award-winning research in the others' area did not improve the computer scientists' status in the eyes of their collaborators. One respondent notes, "… I started looking at [a computer application for a particular field] before the people I tried to work with even had accepted that computers were useful at all! Similar lack of readiness can also be found in more formal work - if one group has no formalism yet for describing what they do … and another group comes in saying they wish to formalize their domain, [that interdisciplinary collaboration] won't work."

Anticipate communication problems, and discuss your language carefully. At the beginning there may be a brief, exciting honeymoon until you hit the methodological and terminological differences. Sometimes, as in the case of a neuropsychologist and an AI researcher trying to match their models for same phenomenon, you may confront deep

assumptions too late.

Remember that learning is required. One respondent noted that "You can't just read the other guy's papers," but you can ask for a few classic papers to read in the other's field. If you know that proximity is out of the question, start well and schedule face time, either on site or at conferences of mutual interest. Work on getting your travel schedules to overlap.

Given their demands, it is easier to break off an interdisciplinary collaboration than one within discipline. One also runs the risk of no results. A researcher who was not an academic pointed out that he could take more risks than his academic colleagues because he could "afford a project failure." Another respondent suggested that "senior folks … have the luxury of playing around and taking risks." Senior faculty who do so thereby encourage their own students to be broad-minded, that is, serve as role models for them. Alternatively, another respondent suggested that graduate and post-doctoral students were ideal for interdisciplinary work because they "had the time and energy to broaden" themselves. There remains, however, the problem of tenure. One respondent described a successful facilitator who had "had his fun [and then had to] settle down to [his] real work," that is, restrict himself to the discipline of his academic appointment as he moved toward tenure.

Another risk of interdisciplinary collaboration is that your results may be unwelcome. One researcher offered another substantial insights that enabled him to create and execute experiments with unanticipated results. The experimenter drafted a paper, but its results did not support the insightful collaborator's theory, so she declined to co-author. The author published the paper alone, and warns "you can't come [to interdisciplinary collaboration] with an agenda."

Of course, interdisciplinary collaboration offers remarkable rewards as well. An expanded perspective is virtually guaranteed. One respondent noted that "… the difference in perspective you gain [by looking at a problem from vantage point of another

discipline] is liberating." Another praised interdisciplinary collaboration because "[It] forces me to think in very different ways." One psychologist, working with a team of computer scientists, found that their questions inspired the design of new psychological experiments even as hers inspired new simulation techniques. Substantial results are often the case; in 12 years of work together, a linguist and a computer scientist co-authored more than 30 papers. Another researcher described a tremendous synergy that was "multiplicative, not additive."

With or without publication, there can be powerful intellectual benefits. Most collaborative results are *co-constructions*; but even better is *appropriation*, "the incorporation of jointly constructed ideas into one's own thinking"(John-Steiner 1998). "Unless it changes you [interdisciplinary collaboration] remains just a division of labor … you need to appropriate some of [the other collaborators'] knowledge … individuals become more effective in formulating problems in ways that their own disciplines do not…." This kind of integration is not necessarily sustained throughout the entire period, but it is a hallmark of the best collaborations.

In our specialized world, many people are doing similar, related work. One respondent notes that "putting their results together is a big win." Interdisciplinary collaboration often provides enrichment and information to other fields. Another researcher enthuses that "Great things can happen that would never be possible otherwise." That includes close personal friendships. One scientist said it very well: "… [one recent interdisciplinary collaboration has been] very intense intellectually … the most stimulating thing I've ever done."

Acknowledgments

My thanks to Vera John-Steiner, who generously shared her enthusiasm and expertise on this topic. I am also indebted to each of the following for their continued interest, enthusiastic support, candid conversations, and thoughtful writing. They are, indeed, superb collaborators.

To appear in *Cognitive Studies of Interdisciplinary Collaboration*

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