Research Team Integration: What It Is and Why It Matters

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ABSTRACT

Science policy across the world emphasizes the desirability of research teams that can integrate diverse perspectives and expertise into new knowledge, methods, and products. However, integration in research work is not well understood. Based on retrospective interviews with 55 researchers from 52 diverse research projects, we categorized teams as co-acting (50%), coordinated (15%), and integrated (35%). Integration, when it existed, usually began when PIs chose collaborators and pursued integration throughout the project. We describe researchers' experiences and research climates that discouraged or encouraged integration. Implications for policy choices and design include changes in team structuring and technology support.

Author Keywords

Teams, interview, integration, collaboration, innovation

ACM Classification Keywords

H5.3. Group and Organization Interfaces [Computer-supported cooperative work]. Evaluation/methodology. J.4 {Social and Behavior Sciences} Sociology

General Terms

Management

INTRODUCTION

> *And so a lot of the code in my group has been written with a computer scientist and an astronomer working side-by, literally, sitting side-by-side at a single keyboard*. (Researcher #19)

Science and technology advances increasingly are efforts performed by teams. Evidence of this change can be seen in the growing number of co-authored scientific papers [34]. Teams and projects at universities are the most prevalent form, but they also exist in industrial laboratories, nonprofit research institutes, scientific alliances, and government agencies such as NASA and NIH. A growing number of projects are large and geographically distributed.

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These changes have been fueled in part by new thinking about how to achieve transformative science. Rather than depending on the gradual flow of ideas from one field to another, scholars and policy makers have promoted interdisciplinary research and training that integrates the contributions of different experts no matter where they reside. Meanwhile, the development of computer-based methods and tools has encouraged a fusing of different technical expertise. For instance, advances in computational biology rose out of collaborations in computer science, statistics, and genetics [27].

To solve large problems in science, environment, medicine, and societal development, funding agencies in the U.S., Europe, and Asia have sponsored a wide range of interdisciplinary, cross-university research programs. Examples are the European Large Hadron Collider to investigate particle physics, the multinational Antarctic Drilling project to investigate climate change, and the Information Technology Research (ITR) program to advance the integration of computer science with other sciences. A vision for these programs is to create innovation that is greater than the sum of the parts. For instance, the preamble to one science workshop in 2009 read as follows:

> Science and technology are at a crossroads. In the past few decades, there has been a compelling thrust toward multi-disciplinary collaborations and a return to the Humboldtian perspective of connectedness. It is critical, however, that more bridge-building occur to fully realize the promises of fast-growing technology areas such as nanotechnology and biotechnology [24].

The CSCW and HCI communities have long led efforts to support team integration with coordination, awareness, and task management tools [e.g., 10]. For instance, SearchTogether, an interface supporting collaborative web search, gives awareness of partner search activity [21]. Other tools are designed to improve primary collaborative tasks such as data exploration [9] and co-authoring [6]. Sunfall, a collaborative visualization tool for astrophysics, allows for synchronous exploration of large datasets [2]. Still other tools serve as a repository for shared work [e.g., 3, 23]. Researchers have also studied design requirements in many collaborative settings, including air traffic control, surgical suites, and medical engineering [e.g., 4, 25].

Despite these advances, theoretical and conceptual advances around the organization of collaborative work and team practices to support integration have not kept pace. A long-standing literature in the study of organizations examines how to facilitate collaborative work and manage interdependencies among collaborators [7, 8, 20, 33]. However, the scholarly community lacks a clear consensus on how integration is experienced in diverse research teams. Further, most technologies emphasize greater communication and knowledge sharing among members but stop short of supporting the integration of expertise and ideas within a team.

To better understand the nature and experience of integrative research, we conducted retrospective interviews with principal investigators (PIs) and co-PIs who had led interdisciplinary research projects. The program that supported their projects provided substantial funding, with a major goal of cross-fertilization and integration across fields and expertise. During this process, we came to realize that integrating a diverse research team's work is a complex and difficult undertaking.

> *We couldn't carve up the tasks very easily. Everyone had to work together on this.* (Researcher #6)

> *We didn't ever really do as much on the bridging as we wanted.* (Researcher #35)

What Is an Integrated Team?

Considerable scholarship in organization science has elaborated how organizations combine their expertise and deploy people in teams [12]. Nordhaug and Gronhaug [26] argue that a knowledge organization's distinctive capability rests on its ability to collaboratively blend specialists from its "competence portfolio" (p. 92). The emergence of fields such as computational biology, and scholarly research, suggests a positive relationship between integration, team performance, and innovation [e.g., 13].

Although the goal of integration is important in many fields, no single definition exists. In organizational science, many authors have drawn on Lawrence and Lorsch's 1969 [17] definition of integration as "the process of achieving unity of effort among the various subsystems … of the organization's tasks" (p. 34). Barki and Pinsonneault [5] define integration as "the extent to which distinct and interdependent organizational components constitute a unified whole" (p. 166). In information systems and software engineering, integration can mean the interconnection of technologies or data [22]. In computer science, teams may create a prototype of a system that requires integration across skills and disciplines. In robotics, the team may build a robot together, requiring integration of software, hardware, sensing, design, and theories of perception and interaction [e.g., 18]. Integration also may be defined as a common theoretical framing of a problem [e.g., 30]. Despite these differences, we can derive a simple definition: *Integration is the extent to which a research team combines its distinct expertise and work into a unified whole*.

Three Levels of Collaboration: Co-Action, Coordination, Integration

Teams collaborate in different ways and degrees. Some teams are groups by virtue of their common membership but members emphasize individual or subgroup work and minimize interdependencies and group goals. We will call these teams "co-acting," a concept that harks back to the earliest psychology of groups [1]. Other teams strive for a greater degree of collaboration. Drawing from Barki and Pinsonneault's [5] framework, we distinguish between activities that coordinate administrative processes, labeled "Coordination" in Table 1, versus activities that integrate primary research operations (e.g., analyzing data, constructing theory, building systems), labeled "Integration." Coordination is achieved through activities such as kickoff meetings, common websites, divisions of labor, and various mechanisms to help the team accomplish work within budget and deadlines. Integration goes beyond coordination; it is a melding of visions, mental models, methods, and intellectual property such that the substantive outcome is a coherent combination of the team's expertise and work products.

Coordination and integration are theoretically related to Thompson's three kinds of interdependence [32]. Coordinated teams have pooled interdependence, in which each part of the team makes a distinct contribution to the whole. Pooled interdependence characterizes loosely coupled teams [29]. Individuals and subgroups do not necessarily work together but they stay in touch, and the team and its management support a coherent vision.

> *We have a really shared vision that this was an important area.* (Researcher #48)

Integrated teams are not only coordinated, but they also have sequential or reciprocal interdependence in carrying out their research practices and goals. In sequential interdependence, the input of one part depends on the prior output of another part.

> *And so in order to do any of the computer vision and machine learning work we needed to have the images.* (Researcher #15)

In reciprocal interdependence, the outputs of each part depend on the inputs of each other part.

> *If you go out with a lot of uncertainty on your measurements, it's very hard to interpret the results ... so, the notion of taking turns and knowing what's the purpose. ... And then the next day, we're going to go and try to explore how some of our instruments work, but if you try to use smarter instruments in the context of not knowing what's going on, it's problematic.* (Researcher #4)

METHOD

To explore these ideas in the context of distributed, multidisciplinary research projects, we interviewed

Table 1. Theoretical distinction between coordination and integration in a research team

Collaboration Attributes	**Coordination**	**Integration**
Focus	Managing research	Conducting research
Description	Coordinated support and management	Integrated workflow, communication, and tools
Type of interdependence	Pooled	Sequential or reciprocal
Illustrative strategies to implement	Project website, kickoff meetings, workshops, project manager	Shared students, shared infrastructure or platform, co-work
Difficulty of implementing	Medium	High
Benefits	Synergy of research, dissemination, innovative institutions	Innovative research, productivity and influence of team's research, interdisciplinary training

researchers who had been funded through the Information Technology Research program (ITR) of the U.S. National Science Foundation.

Beginning in 2000, the ITR program supported interdisciplinary information technology research and education. The program was a major NSF initiative, growing from U.S. $90M in 2000 to U.S. $295M in 2004. Our sample was drawn from PIs and co-PIs with Medium projects (up to US $1M per year) and Large projects (up to US $3M per year). Seventy percent of the ITR projects were funded through the Computer and Information Science and Engineering (CISE) directorate of NSF, and approximately 50% of PIs' disciplines were computer science or electrical and computer engineering. Other PI disciplines ranged widely (e.g., biology, mechanical engineering, physics, psychology).

Sample

We interviewed 55 researchers from 23 institutions and 52 research projects. Our sample was drawn from ITR projects at the top-ranked 100 universities according to their R & D expenditures (70 percent of the sample were in the top 20%). Within this group, we sampled from a geographic spectrum reflecting the spread of ITR projects overall—15 researchers from the Northeast, 13 from the South, 7 from the Midwest, and 20 from the West. We aimed for multiple individuals per institution to help understand differences between and within universities. We interviewed only PIs and co-PIs, principally because they would be most likely to have knowledge of how their entire team functioned, and of institutional factors bearing on the research process.

Interview Protocol

We conducted half- to one-hour interviews that took interviewees through their projects, and in some cases, additional projects. We gave each participant a card outlining the interview topics, adapted from Kraut et al.'s model of research collaboration [16]. Participants were encouraged to discuss their environment for research and their project experiences, how they found their collaborators, planned their budgets and projects, and organized the work and publications. After our initial interviews, we augmented our protocol with additional probes regarding their use of technology, the role of graduate students, team management, and their "lessons learned" from their experience. All but one consented to audio recording of the interview.

Coding

An external service transcribed the interviews, and the authors coded them, aided by QSR International's NVivo 8 software. Our coding method was based on Strauss and Corbin's [31] grounded theory method, in which existing theory is a partial but not limiting lens for interrogating the data. We started by open coding a small sample of interviews independently, compared our results, adjusted and added categories, and then proceeded to open coding of all the data. We repeatedly discussed our findings to cover the experiences interviewees described.

At the second level of coding, called axial coding, we grouped the lower-level codes into thematic clusters and drew connections among them to tell a story about how the projects evolved. As we continued to develop categories, we also compared what we were learning with existing theory. The centrality of our theme of integration evolved from this discussion. Although current theory in CSCW focuses on coordination and collaboration processes, it does not speak much about the integrative processes and outcomes of research projects—are they, in fact, a united whole? We returned to the data to more completely fill in questions such as: Are there different forms of integration? Can a project be experienced as a success even if it is not well integrated? Do incentive structures encourage or discourage integrative projects?

RESULTS

After coding the interviews, we assigned the 52 projects in the sample according to the following three categories:

Co-Acting Teams: We categorized teams that did not substantially coordinate or integrate their work as "co-acting." In these teams, individuals or small sub-groups worked and published separately, with little or no dependence on other sub-groups for their final outcomes. Twenty-six research projects (50% of our sample) were categorized as co-acting.

> *The initial vision I think was also not that strong. It was a little bit more of a potpourri of sub-projects that were tied together by a theme, but they didn't necessarily have a strong collaboration. ... There's many, many publications that came out of it, but they were individual efforts and not, or small group efforts, and not the collaboration.* (Researcher #36)

Coordinated Teams: Some teams coordinated their administrative and support capabilities using mechanisms such as common goal statements, hiring a project director, building a project website, and initiating conference panels, but members did not work closely together on the research itself. We categorized these teams as coordinated teams. Projects in this category included one project whose members created a new department, and two projects whose members started a new conference and sub-field. Just 8 projects (15%) fell into this category.

> *It's almost like the proposal document served as a charter for our department to say, 'This is who we are. This is how we define ourselves. This is a common direction that we want to be headed.'* (Researcher #31)

Integrated Teams: Teams whose members both coordinated and combined their research work and who created unified research achievements were classified as integrated teams. We categorized eighteen projects (35% of our sample) as integrated.

Integration rarely emerged organically. Integrating the work usually required considerable planning and face-to-face interaction, corroborating Olson and Olson's view of tightly coupled work [28].

According to the interviewees, many integrated teams displayed reciprocal interdependence:

> *But wherever we pulled everything together and wanted to create a new functionality, we basically had to work together. A lot of that happened actually by pair coding. So we used a lot, a technique in development, for pair coding where two people write a piece of code simultaneously.… If the two people get along well, it works very, very well.* (Researcher #19)

> *There were definitely interdependencies. ... Each of us had a sense of the requirements for what the other was going to be building and each of them were able to use what the other was doing as a test case of the fulfillment of the bigger vision than either of us could have achieved on our own.* (Researcher #50)

Other integrated teams seemed to be more sequentially interdependent:

> *So that meant our [discipline X] sub team had to go out and collect [samples] and then the ______ engineering team had to build the apparatus. ... And that did create this sort of pipeline dependency that we couldn't work on things until those first two steps were established.* (Researcher #15)

Forces Toward Co-Action, Against Integration

In one of the first theories of group action, Kurt Lewin [19] described how social forces influence groups. This notion seems particularly relevant to the situations described by the interviewees, explaining why so many projects whose funding was predicated on cohesive team effort ended up fractionated into separate individual and subgroup work. We illustrate how such forces played various roles along the course of a project path (see Figure 1).

Initiation Phase

During the initiation phase of the project, project progenitors' main priorities were to assemble a project team and to create a proposal. Proposal criteria, departmental tenure requirements, departmental faculty make-up, and the location of close ties all affected the composition of a project team. NSF proposal criteria favored proposals

Research climate	Proposal criteria Expertise availability Tenure standards	Project budget Student needs Discipline differences Time and distance	Journal/conference preferences
Relationships	Find collaborators Develop trust	Work alone or with others Mentor students	Decide authorship
Tasks	Prepare proposal Plan project	Conduct research Coordinate and manage work	Write papers Present papers Distribute tools and systems
	Initiation	**Execution**	**Dissemination**

Figure 1. Model of research collaboration adapted from Kraut, Galegher & Egido [16] highlighting forces that encourage or discourage integration.

displaying diversity across disciplines and types of faculty. One way to obtain diversity was to increase the number of primary investigators and senior personnel, but increasing the number of project members influenced project structure and the likelihood of integration.

> *I personally think two is a good number and three's okay, but four and above, yeah, it would have to be a really large project with well-managed smaller pieces. I just see that as impractical for the way academia is structured.* (Researcher #11)

> *I think it would be sort of complicated, tedious or boring, probably not very efficient to have say, you know, a weekly conference call with five people, or with five kinds of senior people and a bunch of students. … It's not very productive.* (Researcher #38)

Some researchers found that their local department and close ties lacked necessary expertise so they searched outside for this expertise. Some projects had PIs who had not worked together in the past, but who were added to the proposal for expertise on the topic, and not inconsequentially, to bolster its interdisciplinary credentials. Lack of familiarity interfered with team chemistry and encouraged members to work with team members they already knew (usually in the same department).

> *And it was like, well, why would I want to build a personal relationship and start work with someone else here when I could work with my buddy? It's more fun.* (Researcher #30)

The high competitiveness of the program encouraged putting senior researchers on the masthead, and further, interdisciplinary work, although valued in the abstract, was high risk for junior faculty in view of the tenure clock and department tenure requirements. In consequence, junior faculty were comparatively unlikely to be involved in these projects.

> *I guess in this case the incentives really came from NSF in the sense that I knew that I needed a senior person in computer vision to really have a plausible proposal submission to NSF. If I just did it with a junior person at ______ just starting out it would be a lot higher risk.* (Researcher #15)

> *Even within the computer science community … junior faculty shy away from high- level architecture, network architecture research. They prefer to focus on the design of specific protocols or specific mechanisms. Or, put another way, the more junior researchers, whether they're students or junior faculty, are more conservative in their choice of research topics than senior faculty.* (Researcher #45*)*

> *We tend to avoid tenured track professors on cross-disciplinary teams. We've probably had a few but it's dangerous for them because of the— so the university tenure review process is so hidebound that if they don't have single author papers, and single discipline, then they don't, may not get tenure. So we have to be careful with younger people.* (Researcher #8)

Another component of the initiation phase is writing a plan for the research. Coordinated and integrated teams were more likely to have created, not just a superficial plan, but a shared vision of project goals. Some co-acting teams, however, simply went along with the lead PI's version of the proposal, and only added paragraphs on their specialty. Moreover, team members did not necessarily feel that a shared vision and work plan would have been a good thing to do. They felt they could be highly productive without trying also to integrate their work with a different group.

> *There was really not much, you know, cross-university research. After it was funded, you were able to do research independently. So, you know, a lot of good research came out.* (Researcher #47)

Execution Phase

Key forces in the research climate affected researchers during the execution of their project. These included the project budget awarded, student needs, disciplinary standards (and differences in the case of interdisciplinary work), time constraints (e.g., when funding ended; how long it took students to graduate), and distances among sites.

Funding cuts caused research groups to reassess project plans, resulting in personnel cuts or task elimination. These teams also experienced interpersonal tensions when deciding what parts of the budget to cut. To avoid cutting PIs from the budget, teams scaled back on integration resources.

> *The whole premise of the collaboration was removed in the budget cut, and so we just went our separate ways and worked on our own stuff … The budget cut severed the link between us.* (Researcher #42)

The important goal of training graduate students exerted another very strong force toward co-action. Ph.D. students typically take 5 or more years to obtain their degree, and to win a top job, they usually must publish in their discipline. The PIs on these projects may have intended to use project resources to support groundbreaking interdisciplinary work, but their first responsibility was to their students' need to publish in the top journals of their discipline. Students who branched into a new discipline were viewed as at risk of delay and of facing a sparse job market.

> *It's partly driven by the pressures of publication, because it's related to, for graduate students, 'Can I get a good job after I graduate?' … Me and my group … while they are cross-cutting, there is a pressure, especially coming from the students, that they want to be able to publish, write papers and publish within their own well-defined communities.* (Researcher #45)

Disciplinary differences also exerted cross pressures.

I found that my field, computer science, and maybe some fields of engineering are very goal oriented in terms of we want to get to point A, right, and we do whatever we can to get to point A. And when you interact with the more domain scientists, they're often about understanding basic phenomena. And so while the final goal of we want to try to demonstrate that we can do X with this, if they observe some new phenomenon on the way towards that one goal, they're going to go off ... and try to understand why they're seeing that particular behavior because that's really their reward system, right, is to understand basic phenomena. (Researcher #17)

You start out with some set of faculty and some people don't quite get into the spirit of what you're supposed to be accomplishing ... you know, were willing to talk about collaborating but in practice were much more interested in just focusing on their own group's restrictive efforts. (Researcher #7)

Time was another force. Integration sometimes involved creating a prototype, system, or robot drawing on distinct expertise. Some interviewees expressed concern regarding the finite budget and how difficult it was to integrate tasks before funding ran out.

The integration with [remote partner's] stuff took a while to mature. And actually, the best work that came out of it, came out after, one of my Ph.D. students at least now has a series of papers out some of the theoretical issues we first raised in that proposal. But it took a bunch of years for that to come to fruition. And actually, I think the papers came after the grant was done. (Researcher #30)

And what I've discovered and this may not be true everywhere, but for my students, I pretty much have to work with them for three years to get them to the point where they can begin to be truly productive. (Researcher #55)

Geographical separation exacerbated the effects of lack of familiarity, incentives, and disciplinary differences, as has been documented [e.g., 11]. Eighteen interviewees mentioned PIs moving during the course of the project. Moving resulted in additional communication burdens and budget re-allocations, making integration less likely.

[The] group splintered along disciplinary lines, where, you know, I was attending those meetings, Frank was attending those meetings, we were agreed on what had to be done, but then Frank and I got busy for a period of time, and ... each of us missed three meetings. And the next thing you know, the team essentially began to fracture into two, one that was doing more physics, and the other that was the more social science people. And that, to me, was a big disappointment. (Researcher #52)

Combinations of the forces above pushed teams toward a co-action model of teamwork.

Dissemination

In academia, and in many research labs, tenure and employment at a top institution requires a strong publication record. Additionally, in some subfields, researchers are expected to disseminate new technologies, tools, or systems. Our interviewees believed that the publication system prefers incremental work within the field over cross-disciplinary work.

The nature of how the journal review processes, or the conference program committee process is that perfectly executed work, recording sort of incremental conservative ideas, are more likely to get accepted than high risk, potentially high reward [research]. (Researcher #45)

I think when you address new problems, especially difficult problems, usually it's not appreciated as well in the more established community. So we actually had quite a few problems in terms of publishing our work. (Researcher #54)

But, you know, I sent this paper in to three different places, and eventually it's down the food chain to the ______ *conference.* (Researcher #26)

The process of tailoring interdisciplinary work to specific venues could strain the relationship among collaborators.

Say we might do a piece of research that was very much interdisciplinary and then when you go to publish it you couldn't really publish it in the interdisciplinary way so you'd have to kind of repackage it to fit one or another kind of disciplines. And there was often I would say a fair amount of tension around that. (Researcher #10)

Successful Integration

Despite difficulties and setbacks, and in some cases, the withdrawal of one or members, some teams did manage to achieve substantial integration. One example follows.

The interviewee, "Sam" (Researcher #6), was one of 7 PIs, and an untenured professor when the grant started. The PIs represented three different disciplines and came from six different institutions spread across the US.

It was highly interdependent. This one had to be. We were writing a new code from scratch essentially. We ... couldn't really carve up the tasks very easily. Everyone had to work together on this. And so there was a really tight coupling between the computer science people who were sort of right in the middle where, the middle level of the code and then the chemistry people who were sort of giving their interface part, but then writing the guts down below.

At the beginning of the project, the lead PI, who was "*a big famous guy,*" decided the project wasn't for him.

> *He had his own collaborations going with [other groups] and I think he just wanted to focus on that. He certainly wasn't the kind of guy who was going to get down and write code with the rest of us.*

Unfortunately, this lead PI also:

> *took a pretty big share of [the money]. So ... if we hadn't had him on the grant, I don't know if we could have gotten it funded. I mean you know, to some extent maybe his name was important. But if we hadn't had him, we all could have, you know, a few more people involved.*

Sam and the remaining PIs nonetheless had a shared vision of the project goals and how to achieve them.

> *So the rest of us just took the project and went with it because we know exactly what the goal was and what we wanted to achieve.*

They met at least once every other month.

> *You know, we had to travel and that was just assumed to be part of the project. So I'd say, in order to make it work, you have to really be dedicated to making it work.*

Sam traveled frequently despite having a full workload as an assistant professor.

> *I was an assistant professor and we don't get sabbaticals. So I had to work that in with my teaching schedule and just you know, come and go between classes.*

Also, chemistry graduate students could not be expected to help Sam with the workload due to departmental requirements.

> *You couldn't really get a chemistry Ph.D. doing something like this. If the only thing you did for your chemistry piece, it was to write code, you'd probably fail. There's no chemistry in it. ... Their role was much more supportive rather than direct.*

Working through these various barriers, Sam and his colleagues were very successful, co-authoring many papers in interdisciplinary journals. Also, Sam did get tenure and attributes his work on such a large grant for bolstering his tenure case. Yet given the climate of research and social pressures we have described above, most teams could not rely on the sustained individual commitment of team members. In its place, some teams invoked management strategies that resulted in successful integration.

Management strategies for successful integration

Other than Sam's team, integrated teams had coherent integration plans from the beginning of the project.

> *The dependencies were in the integration of efforts. So each subarea was not highly dependent on the other areas. But the outcome, which was really the theme of the proposal, was in integrating expertise and capabilities and fusing these capabilities to develop an outcome that cannot be done without this integration.* (Researcher #9)

Having a balance of expertise at each site rather than siloed experts helped as well.

> *An awful lot of the work is learning to understand each other's vocabulary. ... I didn't know a lot about her field and vice versa. And so ordinarily I would have a series of face-to-face meetings and we would talk about that in detail. In this case ... she sent us stuff to read and we sent her things to read. ... But it also helped that I had a [other field] junior faculty member ... working on the project as well and so he could act as the translator between the two of us.* (Researcher #15)

Many interviewees mentioned strong leadership.

> *If the [lead] PI is not pushing for it 100 percent, then it doesn't work.* (Researcher #36)

> *Certainly after the funding comes, just communication dedicated to further understanding of and agreement on the significance of the components from the overall picture point of view. Otherwise, experts naturally gravitate towards the aspect that is ... of most relevance to their own scopes of activities. So it's really the alignment of goals and objectives.* (Researcher #9)

> *One of the advantages as I was PI. And I have worked in this cross-disciplinary space for a long time. And so basically people knew I wouldn't tolerate any hiding in your discipline. So it was like if you're not part of this cultural change to meld together across these things then we don't need you on the project.* (Researcher #8)

Lead PIs in integrated teams also required co-PIs to co-author papers and co-advise students.

> *Well, so we try to measure that by doing joint publications. ... We try to measure that by students who are jointly supervised. ... There is of course the carrot and the stick approach. You encourage it by saying how great it is and every time we have a review committee those are the people and the results that are trotted out for everybody see. So obviously people are supposed to get the message.* (Researcher #7)

DISCUSSION

Our results depict integrated teams as a comparative anomaly. As best we could estimate, fully half of the projects were co-acting teams, organized into sub-groups or individuals with little sequential or reciprocal interdependence of tasks and outcomes. A few teams were well coordinated; these teams also performed research separately but came together thematically and administratively, for example, to start a new research conference.

Many forces came together to encourage co-action and to discourage integration. PIs could publish alone with their students and attain eminence. Junior faculty could get tenure. Graduate students could win top jobs. Little in the research system says one must be interdisciplinary or integrative. Normal circumstances surrounding grants such as budget cuts and limited years of funding worked against integration. Virtual organization, especially when paired with disciplinary differences and a lack of close ties also did so. Teams that successfully integrated work had to work hard at it. They maintained a strong focus towards a final goal, employed techniques to support integration such as sharing graduate students or requiring co-authorship, and relied on strong leadership to achieve integration.

According to traditional organization and coordination theory, collaboration occurs when there are interactions and dependencies among project members. In this sense, the co-acting groups we studied were collaborations because members had to write a proposal together, decide how to spend the money together, and report back to the National Science Foundation what they accomplished. However, our analysis suggests that integration requires more than simply interaction and coordination – it requires combining expertise and creating output that is greater than the sum of its parts. Administrative coordination is necessary but may be insufficient to achieve research integration. Our results suggest that some research teams are able to achieve integration, and that the support required to facilitate project initiation, execution, and dissemination for integrated research teams is going to differ from the support required for "normal" research teams. We urge researchers to be more specific about the extent to which integration occurs in collaboration, and extend organization and coordination theory by describing kinds of integration that might occur.

There is an implicit assumption that all integration is good. It is unclear whether outcomes of integrated teams are qualitatively better or have more impact than those of co-acting teams. Not all research tasks require cross-cutting interdisciplinary outcomes for an optimal result. Additionally, it is unclear how much integration is required to maximize benefits to participating fields. Mere exposure to new disciplines may suffice.

Quantitative Evaluation

Although our intent in this paper is to focus on the experience of integration, we were able to draw on archival quantitative data from NSF award information to examine whether integration inhibits or fosters research output in the form of publications. To investigate this matter, we obtained PI publications mined from Google Scholar, Citeseer, Web of Science, and Web of Science Citations.

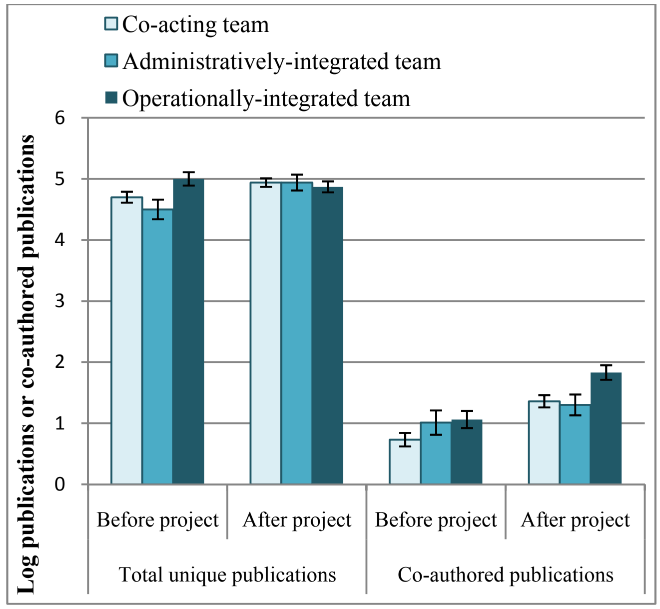

Figure 2. Predicted log publications and co-authored publications by interviewed PIs and their project collaborators before their project started and after it started, through 2009.

We treated these as within-group measures in each project. Figure 2 shows these results.

The values in the figure shown are logged predicted scores and display relative (not absolute) average publications and co-authorship. The analyses and predicted scores control for project year start, number of PIs, number of active NSF grants, number of universities involved in the project, number of disciplines, R & D funding of the universities involved, number of different R& D levels, the publication index used, and the integration level of the project. Also, analysis of post-project publications controls for prior publication rates so they show only whether there were increases in publication rates and co-authorship.

The significant differences found are that integrated teams had marginally more publications prior to their project start date than co-acting teams did ($F [2, 183] = 2.77$, $p = .06$). These differences did not remain after the project started. More interesting for our theme, the different types of teams did not different in co-authorship prior to their project start date, but afterwards, integrated teams co-authored more papers ($F [2, 182] = 4.5$, $p = .01$) and the difference was significantly higher than both other groups ($p < .05$). In short, all groups were equally productive in terms of publication output but integration was associated with more co-authorship.

Limitations

Interviews provide valuable insights into personal experiences but ours do not necessarily provide a full picture of actual events. First, we conducted retrospective interviews, in some cases close to ten years after the start of the ITR project. Also, we (mostly) interviewed only one individual per team and only those with major roles. Other team members will have had different perspectives. For example, graduate students may have offered more insight into the arrangements for students that facilitate integration.

Our results can only speak to experiences at top-ranked universities. The difficulties encountered by well-funded, research-oriented universities may be exacerbated at lower-ranked universities. Additionally, our sample only represents universities within the United States. Collaboration processes differ across cultures [e.g., 15]. We speculate that whereas forces such as distance and tenure pressures may be universal, other cultures might foster stronger team cohesion and integration.

Finally, although our concept of integration depends as much on outcomes as on task processes, our measures are interviewee reports and co-authorship, which might not reflect how integrated final products actually were.

Implications for CSCW

Most CSCW tools seek to streamline task processes and coordination. Integrated teams that have reciprocal integration may require special tools [14]. Our findings suggest that true integration cannot be streamlined; it may require inefficient interactions to reveal synergies between disciplines.

> *So if he asked for something specific, he would be very eager to see it, and …we were always trying to be very receptive to stuff that they needed to get done…Sometimes we would have thoughts about things that we should do and it … didn't really strike a chord with him but we'd do it anyway … because sometimes until you see something it's not really [real]… he could see what he could do with it or he'd get excited about it and sometimes for reasons that we hadn't thought of…* (Researcher #3)

Tools that encourage sharing of intermediate results and encourage task dependencies create opportunities for cross-fertilization of ideas and feedback. In most teams, these opportunities occurred just once a year at an all-hands project meeting. More frequent reports to the whole helped partners develop awareness of task progress and more in-depth mindfulness of other disciplinary cultures and knowledge. Sometimes good ideas could arise out of misunderstandings.

> *Sometimes this misunderstanding actually works out well by accident because I misunderstand what they say and know something which they didn't really say, but it ended up being very interesting and much better than what they would initially do.* (Researcher #18)

However, our interviewees conveyed that tools they tried for sharing tasks or results were not usable or sufficiently motivating to overcome the inertia of local communication.

> *We attempted to create a public repository, and people who were working directly with each other took advantage of it, but nobody else did. So that was basically no technology except for teleconferencing and the video conferencing.* (Researcher #36)

Implications for Research Policy

We speculate that research policy changes within academic departments and funding agencies could better support integration in teams. Departments may need to loosen restrictive systems that do not reward high-risk, long gestation period projects. Even though years had passed since funding for these research projects ended, researchers mentioned that publications from resultant work were still being published.

Our findings also suggest that funding agency pressures to perform and complete projects within three years with a limited budget may act against integration. Some interviewees complained that when funding stopped, their interdisciplinary collaborations had to be abandoned due to changed agency themes, and further, that the systems they invented received no support for further work. They also spoke against pressures to put many PIs on a project, even with adequate funding, especially when PIs would be separated by distance. Our quantitative data also bore this point out: more PIs significantly predicted a lower probability of integration. For tight coupling of research agendas, especially when considering different disciplines, having fewer PIs can help focus tasks and also make opportunities for cross-fertilization easier to plan.

A strong belief embodied in science policy is that putting large teams of diverse researchers together who have a common goal will lead to groundbreaking coherent research findings. Our results suggest that achieving a coherent integrated whole is unlikely and challenge the current policy of favoring proposals with a large amount of geographic and disciplinary diversity.

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