Chapter 19

Collaborative Research: The Good, the Bad, and the Beautiful

William R. Heineman[1] and Richard N. Zare[2]

[1]Department of Chemistry, University of Cincinnati, Cincinnati, OH 45221–0172
[2]Department of Chemistry, Stanford University, Stanford, CA 94305–5080

Interdisciplinary research is on the rise, driven by the lure of solving increasingly complex research problems and a shift in funding trends. The resulting need for broader technical expertise than typically exists in a single academic research group has stimulated collaborative projects, which means they are becoming the vehicle for teaching graduate students how to do research. Here we describe personal observations about the impact of collaborative research on faculty, postdocs, and graduate students.

Introduction

Knowledge is available as a whole. Universities by their composition disintegrate knowledge department by department. Interdisciplinary efforts introduce an important change in mindset to reintegrate information for the purposes of discovery. Increasingly, researchers are becoming aware that solutions to problems do not come with names of departments written on them, but rather require contributions from experts from different fields (*1*). Groups that work in interdisciplinary research are able to multiply their efforts and thus

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have the power to solve many more problems. Yet, as this chapter shows, major impediments exist to these efforts. Here we describe personal observations about collaborations, in particular, the impact of the collaborative mode of research on faculty, postdocs, and graduate students.

Although the success of any interdisciplinary effort requires that departments look outward instead of inward, we are not advocating weakening departments to strengthen interdisciplinary efforts. Indeed, to be successful, these efforts further require that departments be independently capable.

To begin, we examine the drivers for the increased emphasis on collaborative research. First, federal agencies have made available more funds for this type of research. As Federal agencies turn their perspective from long-term fundamental advances to short-term applications, the focus of attention naturally shifts from simple to complex problems. Simple problems are readily assigned to specific departments that serve as important keepers of the truth for their disciplines. Complex problems by their nature demand input from multiple experts who often reside in different departments. Second, there is a growing realization that some of the most exciting problems lie at the boundaries of traditional fields. Third, the dramatic increase in knowledge and sophistication (complexity) of experimental techniques has led to increased specialization. Thus bringing the full powers of all applicable techniques to bear on a problem can require assembling a team of appropriate experts. Fourth, researchers are encouraged to launch interdisciplinary programs because industry states that it wants graduate students who are trained to work on teams as problem solvers. Finally, what the information technology revolution has done to make collaborations possible cannot be underestimated. Once upon a time, researchers exchanged information by mail (in the form of lengthy letters). Telephone connections were possible but prohibitively expensive. Today, communication throughout the world is almost instantaneous by fax, e-mail and even video conferencing at almost no cost. An NMR obtained in one country can be analyzed in another country on the same day. Even experiments can be controlled remotely.

Recent reorganization of the Engineering Directorate at NSF (ENG) clearly illustrates this trend toward collaboration (*2*). ENG is in the final stages of a comprehensive reorganization in which three crosscutting units are being created to facilitate multidisciplinary research. The Office of Emerging Frontiers in Research and Innovation (EFRI) is a major new element that will fund those research opportunities that were difficult to fund under the pre-existing structure. EFRI will focus on "Interdisciplinary opportunities with high potential payoff leading to new research directions and areas that result in a leadership position

and/or significant progress on a recognized national need or grand challenge" (*2*). The changes in funding in ENG are illustrated in Figure 1, which shows that the increase in funding awarded to collaborations has been at the expense of single investigator grants. As stated in 2001 by then Acting Director of the National Institutes of Health Ruth Kirchstein, "The kind of science projects we and the whole world do now...are not small laboratory projects between an investigator, one technician, and two graduate students. They are projects that typically need a lot of resources." (*3*).

Of course, collaboration in science is not a new idea. It is especially common in industrial laboratories where assembling teams to work on projects has been routine for some time. However, collaboration has been far less common in academics. For a long time, there was the ivory tower model: a single professor surrounded by postdocs and graduate students who learned from the professor. At some point, a committee materialized and then approved a Ph.D. dissertation for a graduate student. This is not to say that collaborations have not existed in academics. The Watson and Crick collaboration to solve the structure of DNA is one well-known example. But, in general, collaboration has been far less common in academics than in industry. Why?

The research culture and value system in academics are different from those in industry. Team players who contribute to company profitability are highly valued in industry. Managers can "order" a collaboration---a highly effective approach to "getting things done". However, in the academic world, professors (at any rank) are basically independent entrepreneurs (rugged individualists) who succeed or fail largely on the basis of their individual efforts to establish a strong research program as judged by their peers. Here the reward system comprises novelty of ideas, significance of publications, and prizes, especially the Nobel. Individual credit is the currency of promotion and reputation. The notion of a professor being ordered to work on a project is foreign to this culture. Thus, collaboration is not as easy and has actually been regarded as risky for a young, unestablished investigator, mostly because of perceived vagueries in defining their individual contribution to the field. But the winds of change are blowing. What are the implications for faculty and their students?

A Successful Collaboration?

We like the collaboration shown in Figure 2.

The cartoon shows a diverse team comprising individuals with a history of noncooperation. However, they have a clear, shared goal whose importance

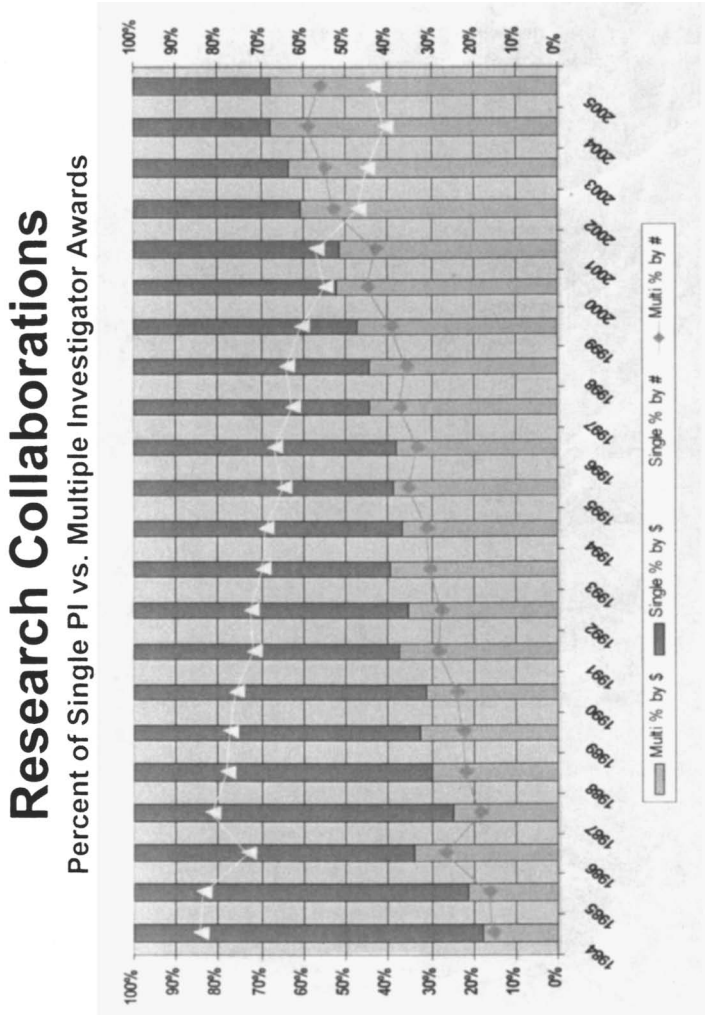

Figure 1. Trends in single investigator vs. multiple investigator awards. (Adapted with permission from reference 2. Copyright 2006.)
(See page 2 of color inserts.)

Figure 2. Cartoon depicting elements of a successful collaboration. (Adapted with permission from reference 4. Copyright 2006.) (See page 2 of color inserts.)

surpasses their individual differences. Having such a goal provides the glue that can hold a team of diverse collaborators together. As shown in the cartoon, a good plan for achieving success is also in place, demonstrating another vital component to a successful collaboration. This team is about to succeed in getting beer out of the refrigerator by working together. But do they have a plan for opening the beverage containers? A real test of the collaboration will determine whether they have all succeeded. Will the larger collaborator decide the collaboration is no longer needed and drink all the beer (he seems to be thinking about that now). Or will he look ahead to the next time they can all work together? Depending on his decision, this could be a successful long-term collaboration with all parties satisfied or a one-time collaboration with only one party satisfied.

In our experience, collaborations work best when one or more of the following elements are in place:

- *Clearly defined goal of high importance.* A clear goal that all parties have a high interest in achieving must be defined. All parties must make a creative

contribution that is important to their own fields. The project cannot be on the "back burner" for any team member.

- *Members working together.* The goal cannot be accomplished individually. Working together will enable all members to multiply their individual accomplishments.
- *Confidence in technical abilities.* Team members must respect each other's abilities in their respective fields. Members must cover their own areas.
- *$$$$.* A large grant can be a powerful motivator. Of course, the team will want to renew the grant, which can serve to keep the effort on track.
- *Suitable personalities.* Suitable personalities are important to long-term collaborations. The ability to work together keeps the team together. One author observed a collaboration that lasted only two days---until the first disagreement between two strong personalities.

The existence of these elements in a collaboration greases the skids of success.

Impact on Faculty

Although collaborative projects have the significant advantages discussed above, becoming involved in a collaboration has definite implications for faculty.

Receiving proper credit for one's contributions is perhaps the most important element because of the academic culture and value system. Assigning credit is relatively easy in a project involving a single professor and the professor's students. However, as other professors/scientists become involved, assigning credit can become increasingly difficult, especially to the outside observer. Although we all want to be recognized for our contributions, the reasons the contributions of each collaborator must be clearly defined and apparent extend beyond this natural human trait. Assistant professors need to create a clear reputation to justify promotion. Important are the external letters of recommendation in which a reviewer is asked to evaluate a person's contributions to a field. Multiauthored papers present difficulties for the external reviewer who might not know the "inside story" regarding the collaboration. Associate professors also face these same issues when being considered for their next promotion. Success with research proposals, invitations to speak, and the receipt of awards are all based on the recognition of individual contributions, and this applies to professors of all ranks.

Based on our observations, some suggestions for dealing with the issue of proper credit assignment are provided:

- Clearly identifying the contribution of each individual generally becomes more difficult as the technical areas merge, making collaboration within the same department more problematic. Therefore collaborating outside one's own department may be simpler in this regard.
- Ideas are perhaps the most important currency in academics and pedigree should be identified. At the outset, agree who had the original idea upon which the collaboration is based. Clearly define the role and expectations of each collaborator. Having each collaborator make a creative contribution in their own field is the optimum situation. Enthusiasm wanes when parties feel they are merely a "service" in support of another person's ideas.
- Multiple publications allow diverse team members to each publish in "their" journal and provide various opportunities for first authorship for the students/postdocs involved.
- When collaborating with very junior faculty, senior faculty must be sensitive to the junior person's special situation and what is best for career advancement. It is easy for senior professors to get all the credit because of their established reputations. Senior professors must go out of their way to ensure this does not happen.

"There are two ways to do something---the right way and my collaborator's way!" Long-term collaboration is much more enjoyable when the investigators are getting along. Flexibility becomes important. Collaborating with the "control freak" can be problematic.

The dynamics of running a research group and mentoring students are definitely affected by the collaborative mode of research. Communication and organization become more important as the manpower and complexity of a project increase with the addition of other research groups. When multiple faculty members are spending equivalent amounts of time advising one student, co-advising provides a mechanism for giving each member credit. If this happens, the student is no longer "just yours" and considering the other faculty member's point of view becomes necessary. Even though the expectations faculty members have of graduate students vary widely, all students should be able to see the big picture and understand how they fit into it. Each student should be given clear charge of a piece of the big project with dissertation rights and first authorship on papers.

Impact on Graduate Students and Postdocs

We now examine the impact collaborative research has on coworkers in the same research group, both graduate students and postdocs. We address primarily

the effect on graduate students, but we believe that the same considerations readily transfer to postdocs. Collaborations have both advantages and disadvantages from the student's perspective. In our opinion, the advantages are considerable. Below are a few.

The Beautiful

The excitement of being associated with a well-organized collaboration that is addressing an exceptionally important scientific problem is the most significant benefit for some. Rubbing shoulders with top people from different disciplines can be a stimulating experience. Seeing the inner workings of a good collaboration provides valuable experience for students intending to follow the collaborative path in their own careers. Inevitably, various points of view emerge about what is significant in tackling the same problem, and these different outlooks and procedures broaden the perspectives and sharpen the problem-solving skills of all those who work together.

The Good

Collaborations can provide considerably broader technical exposure during graduate school. A collaboration often exists because a project requires technical expertise beyond that found in a particular research group. Most collaborations automatically expose the group members to "external" expertise. An example of this exposure is the group meetings where the entire team presents and discusses progress and problems. Such meetings can provide an excellent opportunity for students to broaden their experience by asking questions. Another example is when students from different areas work together and perform joint experiments. This provides real "hands on" experience in the other area. Often students begin to attend seminars in the other departments with which they have collaborated. Of course, the benefits that each student gains depend on the effort expended, which ranges from significant to only the minimum needed to get by.

Greater breadth is good for students to acquire but not at the expense of depth in one's own area. Reaping the full benefits of a collaboration requires more effort by a student. However, this can prove useful later. "Success in industry requires continually developing new skills and contributing in broad areas. Having experienced this in graduate school provides a head start (*5*)." In academics, breadth can be the source of new ideas for young professors to develop their own research programs.

Collaborations provide the opportunity to develop communication and interaction skills, which can be very important to students later in their careers. Communication is key in industrial projects. Effective communication with people from different technical backgrounds is important in industry. The abilities to understand both the entire project and your role in the project, and to explain your work to those who are not expert in your area are critical skills to be learned in graduate school. Collaborations provide students with experience working in a team environment with people from various technical backgrounds and with different problem-solving approaches. "Those who master these skills do the best in industry---accomplish more, are valued more, achieve more personal goals. Already having experience working in a team environment is invaluable for someone entering industry (*5*)."

Although students interact with students from other groups, the extent of these interactions varies greatly depending on the project. For example, in one of our projects, a chemistry student traveled to another university on several occasions for one or two weeks at a time to conduct experiments with an engineering student. The engineering student had developed a device, whereas the chemistry student had developed some biological assays. The goal was to combine the engineer's device with our chemistry and conduct enough experiments to produce a paper. In this case, the engineers could make devices that we could not, and we had biological assays that they did not have. Thus this collaboration exemplified one of the elements for good collaboration: Members each contribute to and control one part of the project within their area of expertise. Because the chemistry student traveled to the other university to do the experiments and wanted to minimize the amount of travel time for cost and personal reasons, the two had to use their time together efficiently. This required considerable planning and coordination of effort. Both students had to have their part of the experiment ready. In the case of the chemistry student, she had to ensure she had everything needed because she would be away from her environment where the usual equipment was readily available. Once together, they had to work cooperatively. Even though the students were not only from different technical backgrounds, but also from different countries, the collaboration worked extremely well. Once the experiments were started some unanticipated problems were encountered, but the students worked together and solved them. Three joint publications resulted from this collaborative project over the course of two years. This collaboration is one example where the efforts of the collaborators are multiplied rather than divided. Several years after graduating and working in industry, the chemistry student commented: "I think back about that collaboration often and am so fortunate to have had the experience during graduate school. As challenging as it was, I learned so much about communication across cultures and disciplines, a skill that is critical to being productive in industry (*6*)."

The Bad???

Here are some problems to watch out for. The responses are direct quotations from former students who have had successful careers in industry/government laboratories.

They are holding me back! A student's progress can be hindered by the performance of other group members. Friction can develop when one student is relying on another student who is not producing at the expected level. This can happen when students are mismatched in technical expertise, motivation, or work ethic. "True, but this is also what you find in industry. Your efforts and work are often dependent on others---team members, managers, those who report to you. Almost everything is interlinked and interdependent in industry (*5*)."

How do I fit into the big picture? As stated above, the contributions of all collaborators must be clearly defined and apparent to them. This applies to students as well as professors. Graduate students need clearly defined projects that they can call their own. (What is clearly defined in the faculty advisor's mind is not necessarily so in the student's!) Students need to know that this material is for their own dissertation. Ownership truly matters in having a successful outcome to collaborative projects.

I should be first author on this paper--not one of them! There can be only one first author on a paper! A graduate student or postdoc is typically the first author on a scientific publication. In coauthored papers with equally important contributions from two or more students/postdocs, first authorship can be a sore point of contention. Producing multiple papers from the students' work solves this problem somewhat by making rotation, if appropriate, of first authorship possible. Ideally, collaboration would enable students to accomplish more. As a result, they would be able to produce the usual number of papers with first authorship as well as additional papers.

Who's dissertation does this go into? There will be some overlap in dissertation material among the students, but the emphais will be different. For example, engineering students would want some results from a chemistry student in their dissertation to validate their engineering projects. Likewise, chemistry students would want a nice design of the device in their dissertations to illustrate why/how the experiments were done. Giving proper credit to the other person is critical. Nothing collapses a collaboration more rapidly than if one party feels that they are only working for the other with no appreciation for their efforts.

I'm working a lot harder than students on other projects. Generally, but not always, more effort is required to understand a broader array of technical issues/areas. For some, it can be intimidating to work with others whose expertise is greater than their own in an area. "True, but in industry the norm is

to work on multifunctional, multidisciplinary teams with varying levels of expertise and opinions (*5*)."

I'm having trouble working with these people. It is more complicated to work across multiple groups with technical, language, cultural, work-ethic, and personal differences. "True, but in reality, it mirrors the business world. Today's work force is diverse (*5*)."

But my coadvisor said just the opposite. Conflicting advice from multiple advisors happens. One student found this "..initially confusing, but ultimately beneficial because it forced me to come to my own conclusions (*6*)."

Meetings, meetings, meetings. "I have learned to value all those group meetings that had nothing to do with my own work. I learned how to focus on very different subject matter. The students may grumble about being stretched and about the number of meetings. They will be glad for it later (*7*)."

Institutional Changes

Thought must be given at the highest level to foster collaborations. This list of recommendations provides a starting place.

- Establish a "culture of collaboration."
- Give due credit to all co-PIs on multi-investigator grants. The restriction of only one PI on a grant is obsolete. All names should be listed in announcements.
- Administer interdisciplinary funding so that each department has its own budget and receives full credit for its share of the grant.
- Give multiple-authored publications equal weight with single-authored papers.
- Review promotion and tenure documents for bias against collaboration.

Conclusions

We advocate collaboration as the way of the future. Graduates entering the industrial sector, where collaboration is already the norm, benefit from working on collaborative projects as students. This benefit will increasingly apply to graduates entering academics as that sector gradually transforms from the historical single-investigator project to more multi-investigator projects.

"Collaborative research shifts the balance on individual mastery to working effectively with others. Both are crucial elements for most successful scientists (*8*)."

Diverse groups working together, making creative contributions to complex problems at the cutting edge, and extending themselves to individually unreachable heights is collaboration at its best.

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