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Research Collaboration and Team Science

WITNESSING THE REVOLUTION

Introduction

The scientific myth of the brilliant solitary scientist has long held sway, the image of the scientist emerging reluctantly from his (yes, it is a masculine myth) laboratory to communicate breakthrough results that will push knowledge ahead in great leaps and bounds. However, in recent decades the myth, one that previously held at least a kernel of truth (Lightman 2008), has become more and more difficult to sustain. While there may somewhere be some future Einstein laboring anonymously while developing potentially earthshaking thought experiments, it is becoming increasingly difficult to ignore the fact that almost all contemporary science is *team* science. In today's science, technology, engineering, and mathematics (hereafter STEM) research, more than 90 percent of publications are coauthored (Bozeman and Boardman 2014). Convincing evidence (Wuchty et al. 2007) shows that coauthored research, as compared to single-researcher work, more often leads to high knowledge impacts as well as to commercial uses of research as reflected in patents. Further, the success of collaborative teams attracts more collaborators, thus accelerating the growth of research teams (Parker and Hackett 2012).

Based on years of research on research collaboration and team science, our book aims to increase the probabilities that research teams will succeed in their collaborative efforts. We are certainly not the first students of research collaboration. For decades, others have studied research collaboration, and much can be learned from these earlier studies (for reviews, see Katz and Martin 1997; Beaver 2001; Bozeman and Boardman 2014). So why this book and why now? The succinct answer is that research collaboration and team science are no longer evolving slowly; in the past few years, researchers have seen and actively participated in a research collaboration and team science revolution. The revolution has many aspects, including the growth in the sheer number of collaborators, but also entails a greater mix in the number and disciplinary diversity of collaborators. We are witnessing a new "collaboration cosmopolitanism" (Bozeman and Corley 2004; Ynalvez and Shrum 2011), as researchers from industry collaborate with those in universities, as researchers from one discipline collaborate with those from other disciplines, and as globalization trends and communications technology facilitate increased cross-national collaborations.

While the research collaboration revolution has, in our view, advanced the technological and human resources brought to bear on research projects and problems, it has also created formidable challenges. The revolution presents challenges with crediting and scientific reputation. Historically, processes for assigning credit for research work were reasonably straightforward: a researcher was or was not the author of a scientific paper and was or was not included on a patent. But the traditional norms for recognition break down when the number of authors proliferates. When there are more than a hundred authors listed for a five-page journal article, what does this signify? Related, new ethical problems have begun to emerge. With one or two or a handful of authors, credit attribution presents fewer challenges, but with expanding research teams the likelihood increases that any particular individual contributed literally nothing. The size and diversity of research teams increases the likelihood of conflict. All things being equal, the more persons involved in a team, the more likely that some team members will not play well with others. Research collaboration is no longer about working with friends at the end of the hall or at the other bench in the lab. With the globalization of teams and increased disciplinary, cultural, and gender diversity, we can see that the challenges for research teams differ greatly from the challenges researchers faced pre-revolution.

While almost all researchers are participating in the revolution, some are barely aware of it (most younger researchers take the current research collaboration regime for granted) and others are so busy with their day-to-day work that they have little time, energy, or inclination to spend much time reflecting on the revolution's implications, much less to develop strategies for steering it in the directions they wish. We feel we can help. Our research is on the social and managerial aspects of research teams and the factors affecting research collaboration.

We provide "front lines" reporting on the research collaboration revolution, as well as evidence-based suggestions about how to improve the effectiveness of modern research collaboration. We employ multiple data sources and multiple research methods, including evidence from survey data, data from Web posts, and archival data, but the core evidence presented in our book is from extensive interviews with active, collaborating academic researchers (those interested in detailed information about our data and methods should consult appendix 1). Our book documents and comments on the research collaboration revolution, even as it transpires, and we suggest how research teams confronting a new and radically changed collaboration environment can work more effectively. A necessary first step in coping with revolution is self-conscious awareness—understanding that it is happening, understanding why it is happening, and understanding its components.

Components of the Research Collaboration Revolution

Twentieth-century research collaboration has much in common with twenty-first-century collaboration, many of same advantages, disadvantages, and problems. But there are several elements of contemporary research collaboration that are quite distinct and important enough to characterize a revolution. Revolutionary changes in research collaboration and team science include changes in (1) the sheer number of collaborations and team members per collaboration; (2) commercialization of academic research; (3) gender diversity; (4) multiculturalism and the global conduct of research; (5) increased multidisciplinary (and interdisciplinary) collaboration; (6) contributorship and ethical issues; (7) a self-consciousness about "team science," including new policies and approaches to understanding and managing research collaboration.

THE STRENGTH IN NUMBERS REVOLUTION

Research collaboration[1] is so ubiquitous that it is not possible to understand the dynamics of contemporary STEM research absent some knowledge of collaborative research in teams. Collaboration is nowadays a concomitant of research. However, the idea of "strength in numbers" relates not only to the increased incidence of collaboration but also to the fact that the number of collaborators and coauthors has expanded greatly in many STEM fields. Recently, a paper (Aad et al. 2015) published in the prestigious journal *Physical Review Letters* included 5,154 authors, such a large number of authors that twenty-four pages of a thirty-three-page article were taken up with the listing of authors. We are confident that four-figure author lists will not become the norm. More important is the fact that the number of coauthors per article has increased in every STEM field (Regalado 1995; Abramo and D'Angelo 2015). Even mathematics, the last refuge of the solitary thinker, has witnessed an uptake in coauthoring (Huang 2015).

At first blush, one might well conclude that the increase in the number and incidence of collaborators is an unalloyed blessing. The fact that most studies show that increased collaboration has positive effect on research productivity seems to reinforce this view (e.g., Li et al. 2013; Ductor 2015). However, there are opposing or more nuanced views. For example, Lee and Bozeman (2005) find that different approaches to citation counts lead to different conclusions about the productivity effects of collaboration and coauthoring. With a "normal count" of citations, assigning one citation to each author, the effects of collaboration on citation are quite positive. But with a "fractional count," dividing credit for citations by number of authors, the number of citations accumulated is not greater than for sole authored papers.

From another perspective, it simply makes intuitive sense that research collaboration, despite possible advantages, is at best net positive, not entirely positive in its cost benefit. Research collaborations offer benefits impossible or difficult to obtain, but they also entail costs. The transactions costs (Landry and Amara 1998) in setting up, coordinating, and managing collaborations vary considerably according to a variety of factors, including the number of collaborators, their familiarity with one another, geographic distance, communications media employed, differences in norms, and goals and incentives, among other factors.

In considering the effects of research collaboration on productivity, one may wish to take into account not only counts of discrete knowledge products (e.g., publications, citations, patents) but also more general impacts on research institutions and researchers' careers (Leahey et al. 2015). One of the most obvious problems arising from the increased number of coauthors is the difficulty posed in the evaluation of contributions. When there are, say, eight coauthors, do they all get the same amount of credit? We could say that the first author should receive more credit, but in some fields the authorship is alphabetical, in others it is the corresponding author who is the leading contributor, and in still others it is the last author who has contributed most. The issues surrounding credit and reputation are not merely a matter of scientific ego. In the first place, tenure, promotion, and hiring decisions are all based in part on the reputation and the credit one receives from publishing refereed journal articles. With large number of coauthors, review committees puzzle over contributions. The task is much more difficult when the multiple author problem is exacerbated by multidisciplinary research teams with diverse crediting norms and practices (Lozano 2013; Egghe et al. 2013).

While the complexities of crediting represent an important problem, much more problematic is the phenomenon of "honorary authorship" (Kovacs 2013), instances where people are included as coauthors but who made no contribution to the research beyond possibly serving as a lab director or providing part of the funds for the study or by just being in need of credit to advance one's career. This is not an isolated issue (Greenland and Fontanarosa 2012); one study (Wislar et al. 2011) of honorary authors and "ghost authors" (ones who made a contribution but were not acknowledged as coauthors) showed that a little more than one-fifth of published biomedical journal articles had distortions in the relationship of actual work to authorship crediting, with most of the distortions owing to honorary authors.

The problem of honorary authors has multiple consequences, some beyond the career impacts of the individual. For example, research grants and contract awards are based in large measure on scientific reputation. One might well feel cheated when losing out in the award sweepstakes to a person who has multiple items on the curriculum vita that do not reflect actual work or expertise on a topic. Even more important, persons with large, publications-based reputations are called upon to testify before policy-making bodies and to serve as consultants for industry. When those reputations are inflated by publications in which they had no part, then the expertise claim might be hollow and the advice provided by spurious experts may be inferior (Moffatt 2011; Greenland and Fontanarosa 2012). When the "expertise" is more apparent than real, the consequences are potentially dire (Kempers 2002; Annesley 2011), especially when the topic of concern has to do with public health and safety, such as, for example, the efficacy of new medical treatments or pharmaceuticals.

As we see in later chapters, research managers and professional groups have made some headway with the problem of assessing the individual's contributions to collaborations that include large numbers of authors and even with the thorny problems of honorary and ghost authors. The basic point, however, is that increased numbers of collaborators and coauthors can present problems. There is no likelihood that the strength-in-numbers approach will diminish. Collaboration is a central feature of contemporary research, a revolution in the way research proceeds, and a phenomenon deserving the scrutiny it is receiving from scholars, research team members, and policy makers.

THE ACADEMIC CAPITALISM REVOLUTION

Academic research, our chief focus in this book, continues to reel from another revolution that has deeply affected the very focus of scientific and technical work, the commercialization of research. For decades, US science technology policy insisted that all federally funded research be public domain and, especially, that patenting and drawing individual commercial benefit from such research, that is to say *most* of the research work in academic science, was forbidden. From the late 1980s forward, the policies related to the disposition of intellectual property from federally sponsored research and development (R&D) changed dramatically, in part due to a perceived crisis in national economic competitiveness (Sampat 2006). The Stevenson-Wydler Act of 1980 made technology transfer a mission of federal laboratories and permitted the labs and even lab scientists in some cases to profit commercially from R&D work performed at the lab. In the same year, the Bayh-Dole Act allowed recipients of federal R&D funds, including private contractors, nonprofits, businesses, and—most relevant for our purposes—universities, to file for patents and inventions from their federally sponsored research. While Bayh-Dole was not at its inception viewed as landmark legislation, history shows that it fundamentally altered research universities and their science and technology activities (Grimaldi et al. 2011), having impacts directly on universities' commercialization and intellectual property, as well as wide-range effects on the structure of research institutions, on faculty career motives and performance assessment, on graduate education, and on university-industry relations. Some critics of so-called academic capitalism abhorred these changes as the selling out of universities for commercial goals (e.g., Slaughter and Rhoades 2004), whereas others, especially researchers assessing effects of the "entrepreneurial university," applauded these new activities as more in touch with economic needs, more likely to produce economically relevant education, and as an important ingredient in regional economic growth (for an overview, see Rothaermel et al. 2007).

Later in this book we review the evidence for the impacts of commercially focused university R&D, but at this point suffice it to say that this set of changes qualifies truly as revolutionary and that its impacts on the nature of research collaboration are in some instances seismic in nature. The most obvious change is a vast increase in university-industry research collaborations and, relatedly, the composition of research teams. But commercialization has also in many cases changed or expanded the motivations for collaborating. On the plus side, collaborations often are more fulfilling as a result of new missions and a new mix of actors. On the minus side, legal issues and differences in institutional cultures often pose problems, sometimes thorny and complex difficulties not present in the pre–Bayh-Dole university environment.

THE GENDER DIVERSITY REVOLUTION

The "great man" theory of scientific advance (Boring 1950) no longer has much veracity, though perhaps the "great person" theory works a little better. In 1973, the year the NSF (2014) began collecting and reporting systematic data on the gender mix of academic STEM faculty in the United States, the 118,000 scientists, engineers, and social scientists included 10,700 women, with the largest proportion of women being in the social sciences. By 2010, the year of the most recently available data, the US STEM workforce had grown to 294,800, including 105,200 women—less than 10 percent in 1973, more than 30 percent in 2010. In some fields of biomedical research, parity approaches.

With the diversity revolution, great changes are afoot in the composition and dynamics of collaborative research teams (Leahey 2006; Tartari and Salter 2015; Gaughan and Bozeman 2016). Empirical studies (Fenwick and Neal 2001; Joshi 2014) suggest that gender-balanced teams are more effective in some important respects, but our previous research (e.g., Gaughan and Bozeman 2016) as well as the new results reported here show that gender-based conflict sometimes occurs in gender-mixed research teams and, even more often, gender-related misunderstandings or uncertainty about the impacts of gender on team interactions. A gender-diverse research team often requires a different skill set managerial approaches than single-gender teams.

THE MULTICULTURAL REVOLUTION

Academic science is no longer the preserve of middle-class white Americans. In fact, immigrants have long played an important role in US research and research teams, with post–World War II providing a prime illustration, as Germans and Eastern Europeans, many of them Jews fleeing the Nazi regime, played leadership roles in American physics, including collaborative work in the Manhattan Project. Before that, scientists and inventors from many places in Europe, people such as Vladimir Zworkin (Russia), Ernst Alexanderson (Sweden), James Franck (Germany), and even Alexander Graham Bell (Scotland) immigrated to the United States and changed the history of science and technology. So what is the multicultural STEM revolution? It starts with numbers and geographic origins.

According to the National Science Foundation (2015a), 5.2 million immigrant scientists and engineers resided in the United States in 2013, accounting for fully 18 percent of the US science and engineering workforce. Among these, 63 percent of US immigrant scientists and engineers were naturalized citizens, 22 percent were permanent residents, and 15 percent were temporary visa holders. But Europeans no longer dominate the immigrant STEM workforce. Nowadays, 57 percent of immigrant scientists and engineers were born in Asia, with India alone providing 950,000 of Asia's 2.96 million immigrant contributors to US science and engineering.

As is the case for most revolutionary aspects of contemporary research collaboration, the multicultural dimension provides great advantages in terms of building the scientific and technical capacity of the United States, but it also can present problems in multicultural research teams that must be addressed. One obvious problem is traversing the legal thicket related to visas, especially since US policies differ by country and over time, including in response to national security and diplomacy issues (Wasem 2012). But most research teams, even if they suffer these problems, do not control them. What we find in our research is that collaborations sometimes are held hostage to the very different cultural norms and expectations that some immigrants bring to the team. For example, one common issue is the differences in the status of women and attitudes about women that one finds in the United States versus some other countries, particularly countries in the Middle East and Asia. But sometimes attitudes also differ with respect to such issues as expressing opinions openly, crediting, and even views about intellectual property. The immigrants often bear the brunt of problems, including feelings of isolation and being "second class" members of research teams (e.g., Le and Gardner 2010).

Thus, even though immigrant scientists are on balance a great boon for the United States (Lowell 2010; Kerr 2013; Peri et al. 2015), it is nonetheless possible to encounter cultural differences playing a role in unfavorable collaboration outcomes. These issues have been little studied, but we provide some evidence here that research teams encounter such problems and develop strategies to cope with them.

Usually the term *multiculturalism* embraces not only immigrants who bring the cultures found in other nations but also US citizens who are part of minority cultures. The impact of US minorities on research collaboration or research in general has not yet had revolutionary effects, chiefly because the percentage of non-Asian minorities in US academic science careers continues to be modest. According to the NSF's (2015b) most recent data on the topic, US universities produced 51,008 doctoral graduates in STEM fields (including social sciences) in 2012, up from 40,033 in 2002. In 2002 the percentage of underrepresented minorities (African Americans, Latinos, Native Americans) increased only modestly during that period, from 8.2 percent to 8.5 percent. When we consider the facts that minorities are somewhat less likely to take faculty jobs and that a significant percentage of minorities take jobs in less research-intensive, minority-serving universities, then we see that the vast majority of research teams do not include minorities (except, of course, for Asians and Asian Americans).[2]

Not only can multiculturalism be observed in US science, but also apparent is the rise of international collaboration in science. Wagner and Leydesdorff (2005) show that the percentage of all documents in the Science Citation Index with coauthors from two or more countries nearly doubled from 1990 to 2000. More recently, Science and Engineering Indicators 2016 reported that internationally coauthored publications grew from 13.2 percent to 19.2 percent of all coauthored publications from 2000 to 2013. Although this growth occurred across all science and engineering fields, it was particularly high in geosciences and astronomy. Several explanations have been given for this increase, including the growth of large-scale science around facilities such as particle accelerators or large biomedical efforts related to the human genome, but this explanation is not totally accurate, because international collaboration can be seen in small-scale science, including papers with two or three authors as well. Other arguments include geographic proximity, national research-building policies, prestige seeking, or reduction in the cost of international collaboration through improvement in information and communication technologies. But whatever the region, this international conduct of research has the potential to raise research collaboration issues.

THE MULTIDISCIPLINARY REVOLUTION

Multidisciplinary research[3] is certainly not new to STEM, and neither are the problems flowing from multidisciplinary teams (Thurow et al. 1999; O'Connor et al. 2003). The revolutionary aspect comes from the vast increase in multidisciplinary collaboration (Rylance 2015). Decades ago, working with "strangers" from other disciplines was sufficiently rare that it seemed almost exotic. Nowadays multidisciplinary collaboration is routine, so much so that some researchers have never been on research teams that are *not* multidisciplinary. Porter and Rafols (2009) investigated changes in interdisciplinary in six research fields between 1975 and 2005 and report a 50 percent growth in the number of disciplines whose journals are cited in articles as well as a steady, though modest, increase in the interdisciplinary acquisition and diffusion of knowledge.

A number of factors contribute to the rise of multidisciplinary research, some of them internal to science (e.g., discovery paths) and others related to active encouragement (National Academies 2005) or policy initiatives such as the emergence of large-scale interdisciplinary research centers (Hackett and Rhoten 2009; Boardman and Gray 2010). Nowadays nearly 30 percent of science and engineering faculty at research-intensive universities are affiliated with interdisciplinary research centers (Bozeman and Boardman 2013).

It is easy enough to see the possible benefits of multidisciplinary research and research teams, including the inclusion of different perspectives, skills, knowledge, and even cognitive styles. However, disciplinary diversity poses problems, chief among these an unwillingness to give sufficient respect or trust to scholars from very different backgrounds (Gardner 2013; Ledford 2015). To be sure, with some care multidisciplinary research teams can be managed effectively so as to limit team problems and enhance research productivity (O'Connor et al. 2003; König et al. 2013) but the increase in multidisciplinary research and collaboration inevitably increases the complexity of research teams.

CONTRIBUTORSHIP AND ETHICAL ISSUES IN RESEARCH COLLABORATION

Ethical problems in science are nothing new. While we tend to think of notorious Tuskegee experiments on humans without their consent as an origination point for ethical concerns in modern science, the case was neither the beginning (Lederer and Davis 1995) nor the end (Mastroianni and Kahn 2002) of problems with human experimentation. Similarly, scientific fraud has of late been much in the news (Hein et al. 2012; Steen et al. 2013), but scientific fraud is probably as old as science itself (Gross 2016). However, in the case of ethical issues pertaining to contributorship, there may be something new and, indeed, revolutionary. In the first place, the fact that collaboration and the number of collaborators have increased to such a degree means that ethical issues of crediting come more sharply into focus. In cases of past decades, when papers were single authored or perhaps had only two or three authors, the need for vigilance about those who contributed nothing was surely not so important. In the second place, we shall see in other chapters of this book that contributorship and crediting issues are contingent in nature.

We shall show in this book that various disciplines and fields differ from one another with respect to what is perceived as a legitimate coauthorship; the same coauthoring norms that are standard and commonplace in one discipline may be viewed as unethical in another. The increase in multidisciplinary teams exacerbates disagreement about crediting norms and ethics. Thus, at least some of the issues related to contributorship are new, largely unsorted, and, in our view, revolutionary.

THE TEAM SCIENCE REVOLUTION: REFLEXIVE LEARNING ABOUT RESEARCH COLLABORATION

Public-policy makers and research managers are well aware of the crucial importance of collaboration in the production and application of research, and they seek to enhance the benefits of collaboration directly through public policies developed explicitly to facilitate collaboration (Boardman and Ponomariov 2014). Recently, changes have occurred with policies implemented at the individual project level. For example, the NSF now requires as part of its annual reports documentation and description of research collaborations flowing from their funded projects. On a broader scale, both the NSF and the National Institutes of Health (NIH) have been quite active in promoting collaboration, both by requiring collaborative teams and by setting up research centers with collaborative missions (Roessner et al. 1998; Zerhouni 2003; Boardman and Corley 2008). Policy makers in the United States have also gotten into the act, especially by developing university and university-industry research centers to promote collaboration (Feller 1997; Plosila 2004).

In sum, it is fair to say that funding agencies and policy makers are very much in touch with research collaboration and the role of teams in contemporary science. One of the manifestations of this awareness is the rise of "the science of team science." NIH policy makers and grantees are at the center of this relatively new initiative, one aimed at developing collaborators' reflexive knowledge of research team dynamics and thereby improving the quality and productively of collaborations. This self-consciousness about collaborative teams can itself be viewed as one of the aspects of the research collaboration revolution.

While it is impossible to identify the exact origins of the formal study of research collaboration, it is easier to identify a specific date for the emergence of a very closely related field, the "science of team science." The term *science of team science* is a recent invention, having been coined in 2006 (or, at least, then coming into common usage) as the guiding name for a conference hosted by the National Cancer Institute entitled "The Science of Team Science: Assessing the Value of Transdisciplinary Research." This ad hoc conference led ultimately to an annual research conference and, in 2008, an influential publication (Stokols et al. 2008) in *American Journal of Preventative Medicine*. The emergence of this new nomenclature served to bring attention not only to the new concerns of the science of team science but, at least to some extent, the existing research on research collaboration. However, this development has come at the expense of some degree of conceptual entanglement.

We define research collaboration as "the social process of bringing together human capital and institutions in the production of knowledge." This is not remarkably different from definitions pertaining to team science. Thus, a Website at a recent science of team science conference (http://www.scienceofteamscience.org/scits-a-team-science-resources, accessed May 29, 2016) tells us that research in the science of team science field aims at "understanding and enhancing the processes and outcomes of collaborative, team-based research" and "understanding and managing circumstances that facilitate or hinder the effectiveness of collaborative science, and evaluating outcomes of collaborative science." This definition, then, seems to suggest only a modest difference between the study of research collaboration and the newer science of team science. Arguably, the most important distinction, one that certainly should not be minimized, is the attraction of the vast US health and biomedical research community to the study and application of research collaboration. Even if the distinction between research collaboration studies and the science of team science is one occasioned by old wine in new bottles, new bottles can be very important, especially when marketing products, including knowledge products. A remaining problem, however, is that work on collaborative teams has become somewhat balkanized. At present, health and medical researchers produce the preponderance of work published to date on the science of team science, whereas very closely related work on research collaboration continues to be produced by social scientists (not directly affiliated with health or medical communities), especially researchers in economics, sociology, and public policy.

This division of labor is not, of course, necessarily a problem and characterizes much of the US research and science policy landscape. For better or worse, the "wall" established long ago between the NIH and the NSF (Kraemer 2006; Stetten 1984), the former being the source of almost all funds for biomedical research and the latter being the source for almost all other academic STEM research, affects a great many domains and effectuates all manner of divisions of labor in research, its funding, its policies, and its management. The specific division of labor pertaining to our work, the one between research collaboration studies and the new literature on the science of team science, proves not particularly problematic. To a large extent the respective literatures are dealing with identical phenomena, including exactly the topics we consider in this book. For this reason, among others, we feel that the work presented here is not only relevant to each field of study, it is integral to each of these closely related fields. One of our goals for the book is to bridge this largely artificial divide and to ensure that two closely related fields that have sometimes ignored[4] one another receive some encouragement to cease doing so. This task is made easier by the fact that the research collaboration and the team science literatures have a common "friend." Both literatures are very much influenced by the core (i.e., not directly about science, engineering, or medical research issues) work in organization behavior and group dynamics. There is mutual recognition that many of the lessons in general theories of team collaboration or in contexts far removed from science and engineering are relevant. While there are some aspects of scientific teams that are much different from, say, product development teams or sports teams, or financial teams, there are many other aspects that are to a large extent independent of the particular focus and composition of the team.[5]

While we feel the differences between research on team science and on research collaborations are quite modest, it is worth identifying the few differences that stem from something more than the failure to do a more comprehensive literature search. First, in the case of the science of team science, there is a greater emphasis on what the NIH has long referred to as "translational research," usually meaning the movement of basic and precommercial research findings into new practices, patents, products, technical advances, and treatments (Treise et al. 2016). In some respects this is not much different from historical concerns with the relationship of research collaboration to knowledge and technology transfer or commercial application (see Bozeman 2000; Bozeman et al. 2015).

Another difference between the research collaboration literature and the science of team science literature is that the former is somewhat more expansive. Both literatures are concerned with something more than the immediate dynamics of research teams; both are concerned with context and environmental factors affective collaborative teams. But the research collaboration literature tends to give more attention to institutional actors and large-scale policy influences and, relatedly, sometimes focuses on organizational and institutional levels of analyses (e.g., such as giving greater emphasis to university industry relations). The study techniques also vary a bit, with research collaboration studies using the same qualitative, case study, and survey approaches as team science but also having much greater use for bibliometrics and scientometrics. By contrast, team science tends to make more use of field experiments.

Despite identifiable differences, our basic point is that research collaboration studies and science of team science studies are much more alike than different. Biomedical researchers, just like researchers in physics, chemistry, and engineering, work in teams, face management problems, have concerns with crediting and reputation, and, unfortunately, sometimes face problems in research ethics, personality conflicts, and intellectual property disputes. Most differences are ones of degree, not kind. In this book we use both literatures and the approaches and methods employed by each. In most instances we make no sharp distinctions between the two. Each approach and each literature speaks to issues and problems of collaborative research teams, and each has important lessons about effectiveness. We see our book as a contribution to the literature and practice of research collaboration and, equally, to team science.

In general, the "science of team science" is a most welcome addition to the study of research processes and outcomes, especially because it signifies not only scholarly curiosity (the genesis of much of the work on research collaboration) but also the commitment of policy makers, research managers, and researchers to develop and use of systematic knowledge of collaborative research teams in order to make them better. In this case, self-consciousness is itself revolutionary.

Surviving and Thriving in the Revolution: Consultative Collaboration Management

The key question posed in this book is: How can one cope with the complexities introduced by the revolution in research collaboration and team science? We have multiple answers to this question, but an important one is related to strategies for managing research teams. In the concluding chapter of the book we present a typology of research management approaches, a typology based on our firsthand observations as well as the data we present here. The approaches include Tyrannical Collaboration Management (fortunately not very common); Directive Collaboration Management (very common); Pseudo Consultative Collaboration Management (with a veneer of democracy painted over a structure of hierarchical direction); Assumptive Collaboration Management (where team members simply assume that all are in agreement about important issues); and Consultative Collaboration Management (not very common but highly effective).

In reviewing these approaches, we discuss their chief attributes and their strengths and weaknesses. However, we come down solidly in favor of one approach, what we term Consultative Collaboration Management. The basic idea of Consultative Collaboration Management is that all team members are consulted at key points in the life of the collaboration (formation, goal setting, task assignment, crediting, disposition and dissemination of intellectual property) so as to identify their respective preferences and values and to decide upon specific actions in pursuit of those preferences and values. We identify more specific elements of the approach and discuss each in detail, elements pertaining to communication structures, assessing team members' contributions, effective means of disagreeing, and identification of diverse objectives, motives, and values. There is nothing magical with this approach, but neither is it in widespread use. However, when it is used, it seems to us to be used to beneficial effect.

Much of the evidence we present in this book is a prelude to our argument for Consultative Collaboration Management. We note here, in our first chapter, that a great many problems in research collaboration are easily avoided. Most problems in collaborative research teams occur not because of malevolence or incompetence but because collaborators assume that other team members share their views and their objectives. However, our evidence shows that most collaborative teams rarely have complete consensus and, equally important, that some members of teams are, for a variety of reasons we document here, unlikely to speak their minds and verbalize their thoughts about the collaboration, especially when their ideas do not accord with other team members.

There is nothing magical about the Consultative Collaboration Management approach. Many of the problems we observe in research collaboration are "textbook" problems of group dynamics (e.g., false consensus, failure to separate judgments of the person and judgment of the idea, a tendency to equate quality in one realm, such as scientific ability, with another, particularly managerial or human relations ability. Solution does not require sophisticated or counterintuitive insights. But the evidence we present here shows that a great many collaborative research teams are essentially on managerial "autopilot" and often to the detriment of the team.

Research Collaboration Effectiveness: Asking the "Simple" Questions

We are concerned with each of the "simple" questions below, but we need to unpack each one. Our questions:

1. What is a "good" or "effective" research collaboration?
2. What are the determinants of research collaboration effectiveness?
3. What can be done to enhance research collaboration effectiveness?

The main reason that these questions are more complicated than they might seem is that different people wish to achieve different things from research collaboration. The multiple objectives for research collaboration mean that identifying determinants of effectiveness and developing approaches to enhancing effectiveness can be a bit tricky. Likewise, and in part because of different objectives for collaborations, researchers do not necessarily have the same concept of the ideal collaborator.

Much of our book is based on interviews, and the ideas and experiences of research collaborators inform all our work. This is a good time to introduce our first bit of researcher evidence, because it impinges directly on what one looks for in a "good collaborator."

THE CASE OF THE ROCK STAR COLLABORATOR[6]

> Adam is a guy I worked with at the [gives name of a government laboratory]. He is considered the father of [gives specialty area]. My most cited paper is a collaboration with him. Working with him is like traveling with a rock star. Everyone would visit the lab over the summer. People

> would come to visit and ask him how he does the calculations. Does he write his own code or buy code? They are surprised to learn that Adam doesn't do those calculations. He has never done anything on his own but he is really good at coming up with the ideas—he is an idea guy—and finding someone else to do that. I was working on some measurements with a colleague and talking with someone outside Adam's office. Adam overheard and he said "these measurements are incredible; we have to write a paper on it". Adam did not really write the paper—I did. But he put his name first. That was suboptimal. But because his name is first, that research is getting a lot of attention. Our papers predated the one that is getting the most research attention, but it came out in *Science* two years after our paper and his paper references his friends. The point is that even if Adam doesn't do anything, a paper he is on will get published just because of his name. A proposal will get awarded just because of his name. So I will include him. In these collaborations—the interpersonal thing is the most important.

So, dear reader, is this a good collaboration, and is Adam really an excellent collaborator? Or is this a bad collaboration or perhaps even an unethical collaboration? Answers depend on who is making the assessment and the criteria being used. Interestingly, the above quote was elicited when we asked, "Can you tell us about the best collaboration experience of your career?"

Thus, we see some of the complications involved in assessing effectiveness. Is a collaboration good because it leads to an excellent outcome, regardless of the behaviors of the collaborators? Is a good collaboration one in which working relations are smooth? Is collaboration effectiveness dependent upon which collaborator is doing the assessing?

With regard to our first question, determining "good" collaborations, one definition of a good collaboration is "a research collaboration that meets its primary objectives, typically objectives involving production of new knowledge or technology." But are all collaborations resulting in a published scientific article best viewed as good collaborations? That seems a low bar. What if the collaboration consumes massive amounts of resources and the scientific results, even if published, are pedestrian, offering little if any significant advance of knowledge? Surely that would not be a good collaboration. Or what if the product of the research collaboration is scientifically first-rate but the process of the collaboration is dreadful? For example, what if one person unfairly seizes all the credit, or if someone of high status or in authority insists on being a coauthor though doing no work on the publication, or what if the collaboration is so rancorous that graduate students involved in the research rethink their commitments to research careers?

Note the passive, impersonal language above: that a "collaboration is a good one if it meets its primary objectives." Subtle but important: this definition treats the collaboration as the unit of analysis, not the individual collaborators. This is not unusual. We often think of research collaborations as entities unto themselves, and in certain ways they are indeed distinct entities, just as organizations, though they are made up of interacting individuals, can be viewed as distinct entities. Even if we think of organizations as distinct entities, most of us have no trouble at all understanding that organizations are social constructs based on the behaviors of specific individuals with specific ties and relationships. In organizations, these diverse individuals sometimes clash and sometimes harmonize, sometimes have conflicting goals and sometimes have converging goals, and some members of the organization contribute productively to the organization's goal, others contribute less. In this respect, most of what we know from studying organizations is directly relevant to the study of the research collaboration entity, the major exception being that the collaborating group may be less formal and is almost always more fluid and changeable.

Just as people in organizations have diverse personal agendas, the same is true of research collaborations. Thus, what is a "good collaboration" for one individual can in some instances be a very bad one for another. How does this happen? It may happen in many ways. For example, let us say that a well-known and powerful principal investigator (PI) and team leader manages a research collaboration team of eight people, all contributing significantly to the creative aspects of the research, and the research is published in a leading journal and is widely viewed as a "breakthrough" article. But let us also say that due to a whim or autocratic decision of the PI, the two neediest participants, say a postdoc and an untenured professor, do not get authorship credit. In such a case, then at least two collaborators may not agree that this is a "good collaboration," even if one genuinely believes that the collaboration has been remarkably successful.

Just one more example should suffice for now. Let us say that an industrial firm has provided substantial funds to a research team, with the express purpose of developing intellectual property that the firm can use. If the research team wishes to publish, that is fine too, but the firm encourages the team to hold off for a few months on publication. The research team takes the money, produces excellent science, but science that has no near-term application at all, then publishes the findings as soon as possible and declares the project both completed and successful. One party to the collaboration (if the sponsor can be deemed a collaborator) will likely not consider this collaboration a success.

These examples show just some of the reasons why it is not always easy to answer the question of what a good research collaboration is. "Good" has multiple meanings, and thus determinants of effectiveness are contingent. What works well for one collaborator may not work at all for another. Fortunately, from previous studies of collaboration (see Bozeman and Boardman 2014 for an overview and critique of the research collaboration literature), we know some of the typical and typically diverse objectives of research collaboration as well as some of the effectiveness contingencies, including such factors as disciplinary composition of the research team, size and geographic distribution of the collaboration, and scientific focus of the collaboration. The importance of such contextual factors also makes it difficult when responding to the final question about approaches to enhancing effectiveness. But having more and diverse evidence helps.

Before delving into the complexities of our data, both qualitative and quantitative, it is useful, we think, to give a summary profile of the questionnaire data on collaboration. This "collaboration arithmetic" is presented below.

Research Collaboration Arithmetic: An Introduction to the Questionnaire Data

As mentioned, our book relies extensively on interviews with researchers, but we also employ questionnaire data based on responses from more than 600 academic researchers working in 108 US universities. The questionnaire data are used throughout the book but provide the primary basis for a chapter focused on decision-making processes in collaboration. Here we present only basic statistics; analysis comes later.

Here we ask, "What are the key characteristics of faculty research collaborations?" We get at this two different ways. In one part of the questionnaire, respondents were asked about the collaboration experiences in the "most recent coauthored research publication." This approach has the advantage of providing a valuable cognitive anchor for the responses—that is, the respondents are thinking about a particular set of experiences around a particular research collaboration that is likely of quite recent vintage. We did not ask them to specify the article; for our purposes it was good enough, though not ideal, that they had in mind one specific research collaboration.[7]

We think this approach proves useful. In the first place, it is not difficult for most researchers to remember the details of their most recent collaboration. Another advantage is that it gives us some insight into the distribution of practices and experiences. If one assumes that examining the most recent publication experience of hundreds of respondents at any particular slice of time represents accurately the diversity of collaboration experiences, then we have a good snapshot. For example, there seems no reason why "the most recent collaborations" should under- or overrepresent collaboration effectiveness for the whole group, nor is there any reason why, in aggregate, the "most recent collaborations" will vary much in the average numbers of coauthors to a paper.

In addition to our interest in this "most recent collaboration," we were also interested in career-long experiences. In a second part of the questionnaire we asked about such factors as career-based percentages of collaborations (versus single-authored work) and possible experience with a variety of negative collaboration experiences. It is perhaps obvious why it is useful to have data looking back at an entire career, but one particular advantage is that some of the negative experiences of interest we knew to be uncommon, the sort of thing that might happen once or twice in an entire career. Since we also had time-based information such as age, rank, and number of years since doctoral degree, having career-based information permitted us to make inferences about the diverse experiences of, say, full professors and untenured assistant professors.

Finally, the full-career questions were likely less threatening than ones about "your most recent collaboration," since it is possible that some respondents were worried about anonymity in the question about one publication in a way they would not be with questions based on their whole careers.

More information about particular methods employed in our survey is provided in other papers (e.g., Youtie and Bozeman 2014), as well as in appendix 2. However, some brief specifications are useful here, at least a sufficient amount as to make clear the nature of the study. Before conducting our Web survey, we needed to determine exactly whom to target for our study. We developed a sampling frame of science and technology fields using the NSF's disciplinary categories in its Survey of Earned Doctorates. Due to previous project decisions, we had decided to exclude the Health Sciences category and Medical Schools. The research collaboration environment in Medical Schools is sufficiently different to render our study too complex. We added one social science discipline to our STEM disciplines—economics—since we thought it would be useful to provide a STEM–social sciences contrast in our study. The resulting sampling frame included, in addition to economics, thirteen disciplines in biology, chemistry, computer science, mathematics, and engineering. The sampling frame called for one male and one female faculty member from each randomly selected department at a given university, because qualitative interviews suggested that gender would be a significant factor; in the event that no female faculty members were affiliated with the department, two male researchers were selected. We sampled specifically for women because a random sample in some fields (e.g., computer science, mathematics) would yield few, if any.

Our sample is from research faculty in STEM disciplines and economics, but only in the Carnegie Doctoral/Research Universities—Very High Research Activity category. We sampled only high research productivity universities, not only because faculty in these universities are more research active and have more research collaborations, but also because most research innovations and breakthroughs and highly cited work comes from those working in these universities. To a considerable extent the Carnegie research extensive universities comprise a different world, one in which research is at least an equal partner with teaching and sometimes, for good or ill, it overshadows the educational mission of universities.

The Web survey, which was concluded in January 2013, yielded 641 nonmedical academic researchers in STEM disciplines in 108 US universities across the United States, for a 36 percent response rate. Respondents were very similar to the population in terms of gender, rank, and departmental discipline.[8]

Who Are the Survey Respondents?

Our survey respondents cover the broad swath of science and engineering researchers. By field, 28 percent are in biology or earth and atmospheric science. Another 27 percent are in chemistry or physics. Engineering comprises 21 percent of respondents, while math and computer science account for 16 percent of respondents. Economics (our social science benchmark) makes up 8 percent of survey participants. The majority of our data come from full professors, accurately portraying the aging of the American professorate (Weinberg and Scott 2013; Finkelstein and Altbach 2014). Of the respondents, 58 percent are full professors, 20 percent are associate professors, and 17 percent are assistant professors, with the remainder being primarily postdocs. Various academic generations are also represented. Of respondents who were PhD recipients, 22 percent received their PhDs in the 1958– 1980 time period, 24 percent in the 1981– 1990 period, 30 percent from 1991 to 2000, and 24 percent from 2001 to 2012. Most of the respondents in our database are Caucasians (79 percent of the sample), while Asians account for 12 percent, Hispanic 5 percent, and African American/Black 1 percent, with the remainder representing another race (0.8 percent) or preferring not to say 3 percent. The distribution of race is, by and large, consistent with the population for academic researchers in Carnegie Extensive universities and STEM fields.

Now we move from "how" to "what" questions. First we consider the extent of collaboration, then differences between male and female researchers in percentage of collaborative research, the extent of working with students in collaboration, and number of authors on the most recent publication.

What Is the Extent of Collaboration?

Looking at collaborative work during the career, we see that, as expected, most studies are collaborative. As is the case generally, the researchers participating in our survey collaborate a great deal in their research (see fig. 1.1 below). Only about 8 percent of all collaborations during

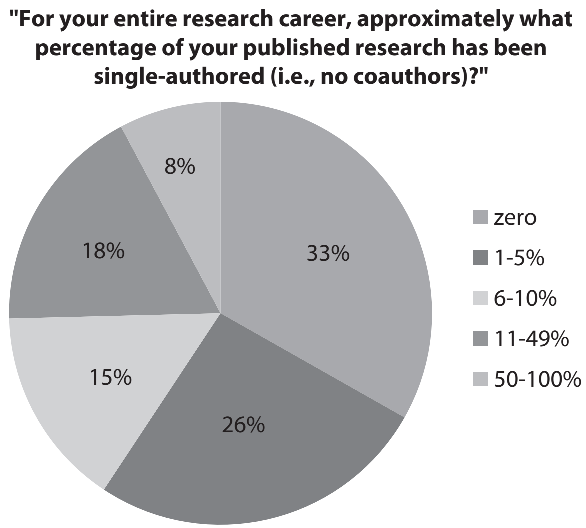

FIGURE 1.1. Career coauthoring patterns.
Source: Research Collaboration Survey. (N = 522 weighted respondents)

the career are single authored. More than one-third of the respondents had *no* single-authored published papers during their entire career. These tended to be younger respondents, especially assistant professors. Another 26 percent said only 1 to 5 percent of their career publications were single authored. Single-authored publications accounting for half or more of an author's career works is very uncommon. Fewer than 8 percent of survey respondents had single-author publications comprising half or more of their career publications, and some of these responses were from very junior respondents with few publications. Single-author publications are much more common in our lone social sciences field, economics. Thus, the notion of academic researchers working by themselves is uncommon (as we expected from previous studies and firsthand experience).

Some of the factors that underlie these results reflect the characteristics of the respondents themselves. Interestingly, female academics were more likely than males to have no single-authored publications (see fig. 1.2). More than 40 percent of female academics had no single-authored publications, compared to 30 percent of male academics. Whether this collaborative nature of female researchers is a result of their positions in the academic hierarchy, their endemic nature, or both is up for debate. It is also the case that female academics are on balance younger, and younger respondents have developed in an environment where collaboration is just a matter of course. But for whatever reason, it is clear that gender differences do exist with respect to collaboration on research papers.

As one might expect, collaboration patterns are somewhat different according to both rank and field. By rank, full professors are much less likely to report no single-authored publications compared to associate and assistant professors. Only 20 percent of full professors have no single-authored publications, while associate professors had twice that percentage (40 percent) and assistant professors had three times that percentage (60 percent). These differences probably do not tell us much about the tendency over time to collaborate but rather about the time required to develop collaborators. Relatedly, many tenured professors collaborate with students and postdocs, which is much less common among untenured professors, who, by and large, give most of their attention to developing a research portfolio that will be sufficient for tenure.

By field, the most striking distinctions concern respondents in the chemistry and physics fields. Nearly half (48 percent) of chemists and physicists participating in our survey have no single-authored publications. These

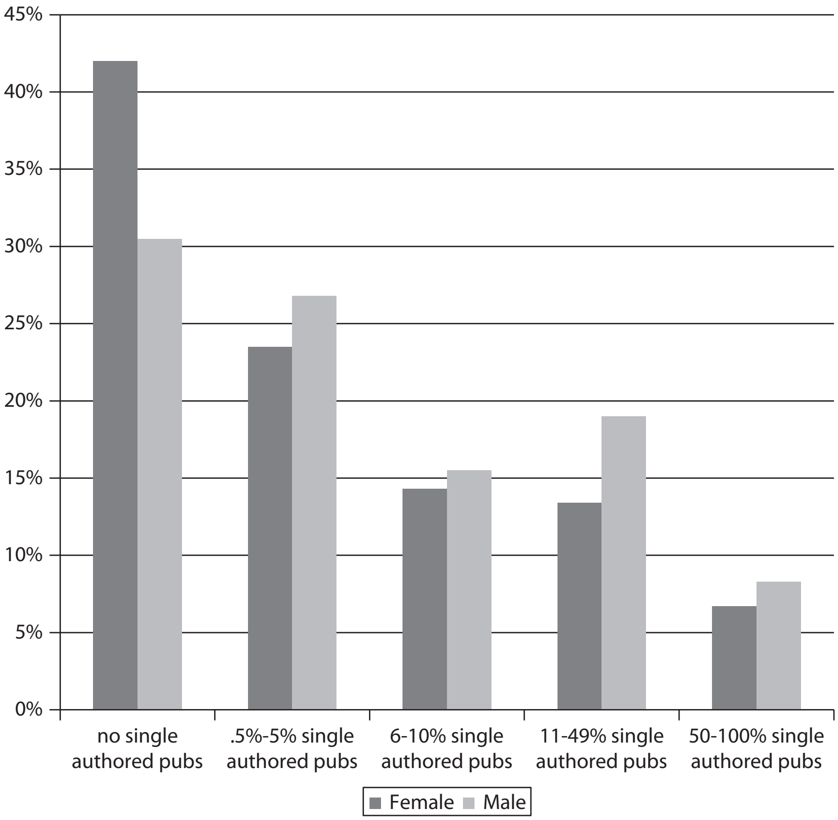

FIGURE 1.2. Male vs. female Collaboration Patterns. Percentage of entire career publications that have been single-authored: males v. females.
Source: Research Collaboration Survey. (N = 522 weighted respondents)

fields, particularly physics, tend to have more involvement in large-scale science. By contrast, only about one-quarter of respondents in biology/earth and atmospheric science (26 percent) and in mathematics and computer science (23 percent) have no single-authored publications. Engineering stands between these two STEM poles at 38 percent. Our social science comparator—economics—shows only 10 percent of respondents with no single-authored publications. Economics tends to by its nature require fewer collaborators (no equipment or large scientific resources) and seems to give greater rewards to the single-authored publication (Ginther and Kahn 2004). Fully 40 percent of the economists who participated in the survey had 50 to 100 percent of their career publications as single-authored publications.

Building the Future: Who Collaborates with Graduate Students?

We asked survey participants, "What percentage of your coauthored papers have included students as coauthors?" Among those who answered this question (519 respondents; a few had no coauthored papers at all), only 6 percent did not have students included as coauthors. The top three most common responses were:

16 percent said that all of their papers included students as coauthors
12 percent said that half of their papers included students as coauthors
9 percent said that 90 percent of their papers included students as coauthors

The mean percentage of papers including students as coauthors was 60 percent (standard deviation of 34 percent), and the median was 67 percent. Males and females are nearly equally likely to coauthor with students. Mean student coauthorship percentages are 60 percent for males versus 56 percent for females. Likewise, there isn't much difference in mean student coauthorship rates by rank: 60 percent for full professors, 57 percent for associate professors, and 60 percent for assistant professors. The main area of difference is by field. Chemistry and physics as well as engineering had the highest mean rates of coauthored papers including students, but they also tend to have larger numbers of collaborators on any single paper. The mean percentage of coauthored papers including students was 75 percent for chemistry and physics and the same percentage (75 percent) for those in the engineering fields (taken together). Mean student coauthorship rates are below 50 percent for respondents in biology and in mathematics and computer science, with the former at 49 percent and the latter at 46 percent. Economics again has the lowest mean percentage of coauthored papers, including students at 25 percent.

Numbers of Coauthors on "Most Recent Publication"

To complement our career-wide research collaboration information data, we also have micro-level information about collaboration on a recent coauthored research publication. Thus we switch to a set of questions about the most recent coauthored research publication. By way of background, the most recent coauthored paper had the breakdown of respondents by number of authors according to fig. 1.3.

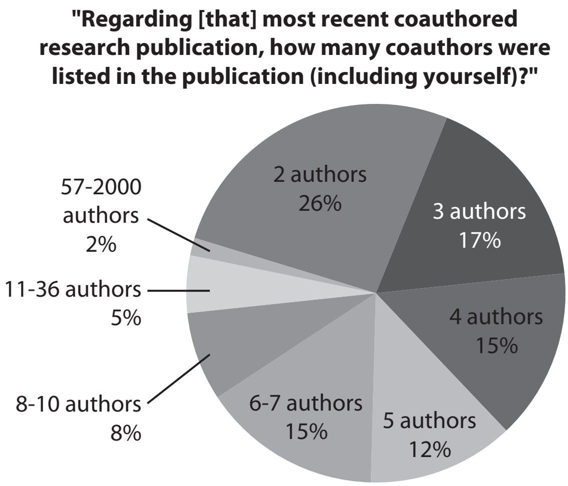

FIGURE 1.3. Number of coauthors.
Source: Research Collaboration Survey. (N = 635 weighted respondents)

In other words, while two-authored publications represent the modal response—with 26 percent publications being two authored—they by no means comprise the majority of coauthorship configurations. Moreover, a few of the papers have "hyperauthors" (Cronin 2001) involving more than fifty authors. The papers examined here tend to be recent ones, as one might expect from a query about "most recent published paper," and they tended to be rather recent. Of these, 71 percent were accepted for publication in 2012 and 16 percent in 2011.

Gender preferences are observed in our survey responses. Male respondents were more likely to work with males in their most recent publication and females with females. Among males, more than half of the coauthors of male respondents were males only. In fact, only 6 percent of male survey respondents did not work with another male coauthor. For females, only 11 percent of the coauthors of female respondents were female only, but only 5 percent of female respondents did not work with another female coauthor.

How cosmopolitan are researchers in terms of their choices of collaborators? Respondents had a tendency in their most recent collaborative paper to work with at least one coauthor at their home university. Consistent with previous findings from our collaboration studies (Bozeman and Corley 2004), most respondents (77 percent) worked with at least one coauthor from the home university of the respondent. But collaborators from other universities are also common, with 80 percent of all respondents having at least one coauthor from another university. Consistent with other studies (Lin and Bozeman 2006; Boardman and Ponomariov 2009), a minority of researchers (18 percent) has even one coauthor affiliated with a private firm.

In the most recent coauthored paper, 26 percent of survey participants were lead authors. First authorship was more likely in papers with only two coauthors (the respondent was the first author in 42 percent of these papers) or only three coauthors (the respondent was the first author in 36 percent of these papers). Otherwise, the respondent was the first author in fewer than 20 percent of the remaining authorship configurations. To some extent, we can expect that the number of authors relate closely to the likelihood of an individual being first author in any particular publication.

In making sense of the lead author phenomenon, it is useful for the reader to understand something we found as part of this work: that "lead author" has different meanings in different fields. In some research fields and disciplines, being the first author is vitally important, in others it is most desirable to be the *last* author, and in still others what is important is being listed as corresponding author. In only one discipline, economics, is it common to have author order alphabetic. We come back to these issues, which can prove surprisingly thorny and contentious, in our later chapter on "contributorship" and coauthor decision-making.

The Rest of the Book

By this point, the reader should have a good idea of the basic objectives, approach, style and overall tenor of the book as well as some initial insight into the data we employ. While each of the chapters provides a distinctive contribution, they share a common goal: the desire to shed light on research collaboration effectiveness in general, and either by implication or empirically based "lessons for practice," to suggest steps researchers can take to improve their own collaboration experiences. One of the primary contributions of the book is to provide conceptual tools for thinking about research collaboration. We first pursue this goal in chapter 2, introducing a simple typology of research collaboration outcomes, emphasizing that most research collaborations are positive but that the ones that are not are often quite damaging. We use our interview data to illustrate the range of research collaboration outcomes. For the pessimists among our readers, we show that some research collaborations can be viewed as Nightmare Collaborations, where everything seems to go wrong and with dire consequences, including exploitation by the powerful of the less powerful or less experienced, unethical behavior, personal attacks, and such. These types of collaborations oftentimes lead to such outcomes as lifelong professional recrimination, law suits, besmirched reputations, and people abandoning research altogether. The optimists among our readers will be gratified to find just how uncommon are Nightmare Collaborations and will be buoyed to learn that the vast majority of research collaborations are quite successful, especially in terms of the perceptions of participants.

We expect this book will be of interest to two quite different constituencies, the large group of researchers interested in improving their research collaborations and the smaller group of researchers, chiefly social scientists, who study either research collaboration or related social and economic aspects of science, technology, and research. Chapter 3 provides a succinct review of literature on research collaboration, one that includes the most recent findings about research collaboration and the science of team science. Many of the readers in group two, those conducting research on collaboration and related topics, will find their work discussed in chapter 3 but may also benefit from the organization and synthesis of the literature. The larger group, those interested more in managing and improving their own collaboration experiences than in the nuances of research and theory about collaboration, should be able to tease some relevance from the various results reported in chapter 3. Both readership groups may wish to consult our appendix 2, in which we provide a companion literature–based propositional inventory. This inventory is both more extensive and, at the same time, less so. It is more encompassing because it provides even more research findings about collaboration, but there is little commentary or assessment, and in that sense it is more limited. We hope that the appendix provides a readily accessible tool for science and technology studies researchers while at the same time it furnishes a quick reference for researchers seeking results related to specific collaboration issues they may be encountering.

In chapters 4 and 5, closely related to one another in both purpose and style, we begin to get serious about in-depth presentation and analysis of the data we developed for this study, beginning in chapter 4 with an analytical framework we feel is one of the more important contributions of the book and then applying the framework in chapter 5 to the data. Chapter 4 introduces our Aggregate Model of Research Collaboration Effectiveness and chapter 5 applies it, chiefly with reference to the interviews developed for this book. The Aggregate Model of Research Collaboration Effectivness identifies a number of determinants of research collaboration effectiveness, largely based on the research literature reviewed in chapter 3. The model includes collaboration management processes as a key factor, one that receives relatively little attention in the research literature but one that is featured here as one of the major instrumental approaches to improving collaboration effectiveness. Why focus especially on collaboration management? Since our book is focused on the individual researcher, with the assumption that the researcher will be interested in learning about and possibly improving his or her own research outcomes, we take special care to emphasize those factors over which the researcher has some control. Thus, while such factors as government and university policies may have strong effects on research collaboration experiences, most researchers do not have much control over these factors. By contrast, researchers often play a major role in their collaboration choices and the management of collaborations.

While chapter 5 makes extensive use of our interview data, chapter 6 focuses on our survey data and examines the motives, activities, and decision processes of the respondents' reporting about their research collaboration experiences. The two key parts of the chapter are responses to, first, questions about respondents' most recent collaboration and, second, about the collaborations they have experienced throughout their career. The data show that the vast majority of researchers experience some negative collaboration outcomes, but only a minority of specific collaborations entail bad outcomes (such as colleagues who did not produce work promised, extensive delays, crediting issues, exploitation, or gender conflict).

Our concluding chapter, chapter 7, is in some respects the most important, because it is here that we draw some lessons from our data and research about how specifically to improve research collaboration teams. In this chapter, we distill lessons from the Aggregate Model but then present an observation-based typology of research collaboration management, including the Consultative Collaboration Management approach that we feel has potential to increase the likelihood of effective collaborations.

Consultative Collaboration Management, generally our preferred approach, is not the most common approach to collaboration management. That distinction rests with Directive Collaboration Management, whereby one of the collaborators is, essentially, the person in charge. The directive manager may or may not consult other team members on important decisions but, in any case, provides the last word on decisions about such factors as collaborator recruitment, specialization, and crediting. Why is

Directive Collaboration Management so common? The approach reflects hierarchies one finds in science and engineering research and practice. Often the directive collaboration manager is the laboratory director, the principal investigator, or the dissertation or postdoc supervisor and easily gravitates to the notion of being in charge, generally with the assumption and often the reality that others acquiesce.

A less common collaboration management approach is the one we refer to as Tyrannical Collaboration Management, an approach that in some ways resembles Directive Collaboration but can be thought of as its pathological counterpart, characterized by desire to dominate and little or no respect for others' opinions. Tyrannical Collaboration Management is often associated with the Nightmare Collaborations we discuss in chapter 2 and elsewhere in the book.

There is no need here to summarize all the collaboration management approaches identified in chapter 7, but it is worth underscoring that any of the various approaches to research collaboration management, with the possible exception of Tyrannical Collaboration Management, can under the right circumstances be effective. While we feel that Consultative Collaboration Management generally offers the best hope of enhancing effectiveness, the real key to effectiveness is fitting the management approach to the needs and the resources of the specific collaboration. Thus, for example, a team of collaborators who are experienced, who have collaborated with one another frequently, and who have easy access to one another's time and attention will have very different needs than will a team that includes people not well acquainted with one another, who have diverse perspectives and backgrounds, and who have different statuses. In short, one size does not fit all, and as we review the findings throughout this book, that is a good point to bear in mind.