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Demystifying the Academic Research Enterprise

Becoming a Successful Scholar in a Complex and Competitive Environment

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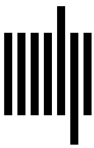

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13

I Need You and You Need Me: Collaboration, Multidisciplinary Inquiry, and Academic-Corporate Partnerships

Chapter Overview and Learning Objectives

Because many of today's most intellectually stimulating, societally important, and personally rewarding challenges lie at the boundaries of multiple disciplines, collaboration among researchers increasingly is important, even to the point of having its own descriptor—*convergent research*. Such collaborations come with unique challenges that must be recognized and addressed if team-oriented and multidisciplinary research are to succeed. Additionally, collaboration extends beyond the academic realm to engage other sectors (e.g., private industry, nonprofit organizations, government organizations), and numerous funding programs exist, across all disciplines, to stimulate such collaborations via the creation of professional networks, public-private partnerships, research centers and regional hubs, and other mechanisms emphasizing regional economic development and community transformation.

This chapter highlights the purpose and importance of research and creative activities that engage multiple individuals within a given discipline, multiple disciplines, and multiple sectors of the research and innovation enterprise. It also addresses challenges in tackling boundary-spanning problems as well as key characteristics of successful research teams and strategies for creating and managing them. After reading this chapter, you should

- Understand the history and importance of research collaboration and the various ways in which multiple disciplines can work together to solve problems residing at disciplinary boundaries;
- Understand and be able to distinguish among the modalities of research involving one or more disciplines;
- Be able to explain barriers to collaborative research;
- Understand the characteristics of successful research teams and be able to apply those characteristics to your own work as appropriate;

- Be aware of funding opportunities and other resources that support building collaborative networks, centers, and hubs both within academia and with other sectors;
- Understand the importance and basic tenets of multisector collaboration and the factors which tend to inhibit it;
- Understand ways in which to initiate collaborations and partnerships with nonacademic organizations; and
- Be familiar with ways in which academia and corporations can partner beyond sponsored research activities.

13.1 Lexicon, Challenges, and Opportunities of Collaboration

In the earliest days of intellectual inquiry, philosophers, many of whom also were theologians, generally worked alone, focusing on their individual views and theories regarding spirituality, philosophy, the human experience, and the natural world, though of course corresponding with others in doing so. The names of pioneers are familiar: Aristotle, Socrates, and Plato. A millennium later, this same modality remained dominant with the likes of Galileo, Kepler, and Newton, who published principally as sole authors, though building upon previous works in advancing knowledge. In fact, paying homage to those who paved the way for him, Sir Isaac Newton said the following about his own work: "If I have seen a little further, it is by standing on the shoulders of giants" (Newton and Hooke 1675).

We focus in the present chapter on two important and related topics: collaboration within and beyond academia, and inquiry involving more than one academic discipline. In its broadest interpretation, collaboration—which in the context of science is known as team science—involves two or more individuals working together to achieve a common goal or set of goals, stimulated by the fact that each brings something unique or valuable to the effort.

For example, hundreds of physicists can collaborate to understand the nature of exotic particles generated in billion-dollar atom smashers, such as the Large Hadron Collider in Europe, while three or four musicians can collaborate to create a score for a musical. In these cases, most or all participants are in the same general discipline, though likely having different areas of expertise and perspectives. On the other hand, inquiry involving scholars from multiple disciplines is another form of collaboration, which again brings together researchers working to achieve a common goal. An example is civil and structural engineers, social scientists, urban planners, and architects all working together to study and make recommendations about how to reduce the impacts of severe flooding within a city.

As detailed in section 13.5, collaboration does not reside exclusively within the walls of academia, but rather can involve organizations in other sectors, such as private companies. For decades, faculty and other academic researchers have collaborated with industry, in some cases via formal partnerships, resulting in research outcomes supporting the development and marketing of new technologies and even the creation of new private companies. Such partnerships sometimes bear other fruit, including endowments to academic institutions for buildings, facilities and professorships. It is important to recognize that private companies are not banks to which academic researchers can turn for funding. Rather, they exist and survive by making a profit, keeping shareholders happy, and being competitive in the marketplace of ideas and products viewed as valuable by consumers. Consequently, academic-corporate partnerships must be pursued with proper motivation and a full understanding of the value proposition for all involved.

Not surprisingly, the lexicon of collaboration is a bit more nuanced than just portrayed, irrespective of the disciplines or types of organizations involved. When everyone on a collaborative team is from the same discipline, the term *intradisciplinary* or *unidisciplinary* collaboration applies. The aforementioned music example fits this definition. At the other end of the spectrum, if members of the team are from different disciplines but draw only upon their disciplinary expertise in the collaborative work, the term *multidisciplinary* applies. The aforementioned flooding example fits this definition.

Cross-disciplinary collaboration occurs when researchers view their work through the lens of other disciplines. For example, a physicist working on the fundamental properties of matter at the atomic scale seeing her work from the perspective of a private sector engineer who develops synthetic materials arising from it. In such cases, the dependence of one field upon the other yields important insight regarding approaches and ultimate goals.

Interdisciplinary collaboration, on the other hand, involves integrating and synthesizing perspectives from multiple disciplines. A good example is the development of new weather forecast guidance by integrating the expertise of federal government and private sector operational meteorologists with those of academic communication and behavioral scientists who know how forecast information can best be organized, communicated to, and interpreted by the public.

Finally, *transdisciplinary* collaboration takes place when disciplinary perspectives are combined to create a new, unified framework of theories, models, and approaches. A fun example here, for those of you who are foodies, is fusion cuisine, which is cuisine that combines elements of different culinary traditions to arrive at something new and different. An example more relevant to research is biomedical engineering, which now is its own discipline and

represents a true fusion of chemical engineering, material science, biochemistry, physics, mathematics, and computer science.

Recently, the term "convergence" has been used to give specific meaning to transdisciplinary collaboration. The National Research Council (2014) defines convergence as "an approach to problem solving that integrates expertise from life sciences with physical, mathematical, and computational sciences, medicine, and engineering to form comprehensive synthetic frameworks that merge areas of knowledge from multiple fields to address specific challenges." The report goes on to note that "Convergence builds upon fundamental progress made within individual disciplines, but represents a way of thinking about the process of research and the types of strategies that enable it, as emerging scientific and societal challenges cut across disciplinary boundaries in these fields."

For now, it is important to recognize that collaborative research, no matter the specific form it takes or the types of organizations involved, is challenging and involves addressing a number of important questions at the outset. How do I know if I need collaborators? Where do I find them, especially if they are in another discipline or located at another institution? How do I know if someone will work with me? What are the characteristics of a good collaborator or set of collaborators? How do I learn to work with someone or several individuals from a completely different discipline, where words I use in my own work have different meaning to them, and where each of us uses completely different methodologies for solving problems?

Though collaboration can be challenging, it also is extremely valuable as well as rewarding. Why? First and foremost, because it allows you to tackle problems beyond your particular area of expertise, and even pursue problems outside your discipline. And second, it brings other important resources to the table that you otherwise would not have. Facilities. Ideas. Funding. Reputation of collaborators or their organization. Linkages to others and their networks. Collaboration expands our horizons. It also challenges us, and provides opportunities for us, to go beyond our own ideas and ways of thinking.

In fact, some of today's most interesting, challenging, and societally relevant problems require collaboration because they reside not within a particular discipline—though such problems obviously do exist—but rather at boundaries among multiple disciplines. Examples include tissue engineering, which combines medicine, chemical engineering, biology, mathematics, and computer science; digital humanities, which combines computer science, classics, history, library science, and anthropology; and environmental impacts on food production, which combines atmospheric science, agriculture, plant biology, microbiology, social science, and hydrology.

Figure 13.1 underscores the importance of collaborative research, showing that the percentage of publications involving more than one author has been increasing over the past sixty years. Additional detail can be found in figure 13.2, which provides a breakdown of publications by number of authors. Incredibly, some papers have more than 1,000 authors!

13.2 Disciplinary Research and Education in a Multidisciplinary World

Not surprisingly, and quite obviously, multi/cross/inter/transdisciplinary research is impossible without individual disciplines. Yet, one of the greatest barriers to academic scholarship involving more than one discipline is the irony that most colleges, universities, and even funding agencies are organized around disciplines! For example, most universities have within them colleges of arts and sciences, engineering, humanities, business, education, and fine arts, to name a few. More recently, discipline-spanning colleges have emerged, such as in biomedical engineering, environmental science and sustainability,

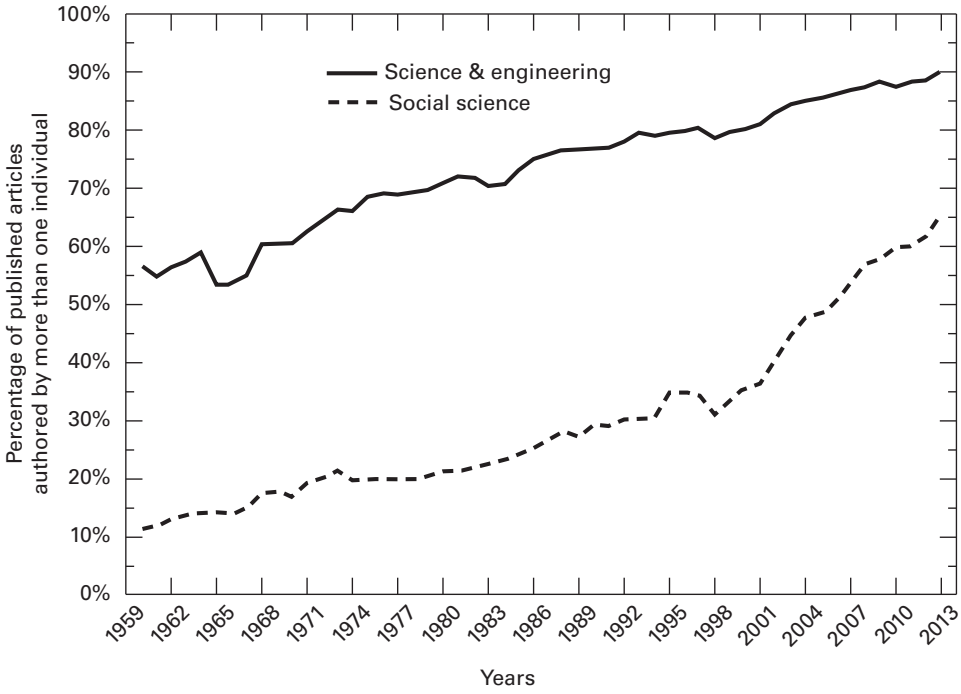

Figure 13.1
Percentage of publications authored by more than one individual during the period from 1960 to 2013. *Source*: National Research Council (2015).

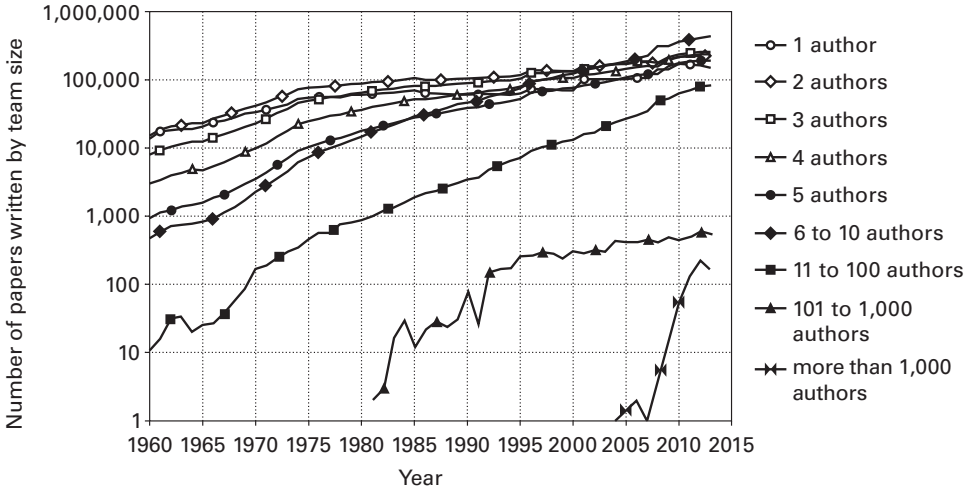

Figure 13.2
Frequency of author team sizes in science and engineering during the period from 1960 to 2013. *Source*: National Research Council (2015).

and data science. Within such colleges are housed individual departments containing specific disciplines, such as physics, mathematics, psychology, sociology, art history, sculpture, modern dance, and electrical engineering. This structure has been with us for quite some time.

Indeed, as noted in the preceding section and in chapter 3, academic disciplines arose over several centuries, though during the eighteenth century, greater emphasis was placed on topics such as history, geography, geometry, algebra, modern languages, and astronomy. Additional emphasis on biology and physical science led to an increasingly complex intellectual and societal landscape, and then in the late nineteenth and early twentieth centuries, the disciplines of sociology, psychology, anthropology, economics, and others emerged in support of agriculture and the mechanical arts, especially at land-grant institutions. Students seeking higher education degrees in the first two-thirds or so of the twentieth century tended to focus mostly on their chosen discipline, such as physics, chemistry, engineering, or mathematics, with electives and areas of emphasis outside the discipline becoming ever more popular.

Today, in addition to a degree in a given discipline, one can obtain a variety of formal credentials in areas other than one's chosen academic major, such as minors, areas of concentration, certificates, and badges. One also can obtain multiple degrees in different disciplines, a degree with multiple majors, or even a customized degree that combines courses from multiple disciplines, such as law, physical and behavioral science.

In this environment of increasingly rich opportunity and intellectual vitality, which includes the study of discipline-spanning problems, comes several interesting challenges. First, the administrative college and departmental structure of academic institutions today—sometimes referred to as disciplinary "stove pipes"—can create barriers to collaboration because different disciplines, and the academic programs that house them, have different philosophies by which they operate. They also tend to have different and often conflicting reward structures.

For example, one discipline might not value the publication of research outcomes in the journal of another discipline, and thereby the associated incentives for researchers to pursue multidisciplinary work are diminished. Also, although colleges and universities have improved the manner in which they recognize and reward collaborative research, the academy remains centered largely around measuring outcomes at the level of individual researchers. For example, how many papers *you* published, how many performances *you* gave, how many exhibitions at which *your* work was presented, and how many grants *you* received.

For this reason, most colleges and universities allow faculty to create or pursue funding to establish multidisciplinary centers and institutes. This construct allows multiple faculty and researchers from across an institution, perhaps working with colleagues from other institutions, to collaborate effectively and establish their own management and reward structures apart from traditional university colleges and academic departments. Though such frameworks face their own sets of challenges, they have proved to be an effective mechanism for tackling boundary-spanning problems. More information about them can be found in the references (e.g., Kezar and Lester 2009; Lyall et al. 2011; Bennett and Gadlin 2012; Lyall and Meagher 2012).

Second, with regard to funding agencies and private foundations, most continue to be organized in a manner similar to colleges and departments in academia. That is, they are structured around traditional disciplines such as mathematics, life sciences, physical sciences, engineering, social and behavioral sciences, and so on. Although this sometimes makes difficult the review of grant proposals involving multiple disciplines, the situation has improved markedly over the past twenty years. In the same manner that many academic institutions now house multidisciplinary research centers and institutes outside of discipline-based academic departments, funding agencies and also private foundations have a plethora of cross-cutting programs that bring many disciplines together and offer mechanisms for attacking boundary-spanning problems.

Ultimately, it is wise, in obtaining a degree or multiple degrees, to garner some level of expertise outside of one's core discipline, via the mechanisms

described previously. Why? Doing so enables you to tackle boundary-spanning problems. Also, it no longer is the case for most people that one obtains a degree in a particular discipline and then works in that discipline for the rest of their lives. In fact, one must today be able to reinvent themselves, usually multiple times, over the course of a career to adapt to rapidly changing technology, challenges, and opportunities. Obtaining formal expertise outside your chosen discipline is wonderful preparation for lifelong learning and gives you the ability to adapt and respond to opportunities in the future.

Yet, a word of caution is in order along these lines with an important caveat that depends upon the pathway you wish to follow in your career. One must be mindful, in obtaining formal expertise outside a core discipline, to avoid in some career paths becoming so broad as to not have a clear identity. As an example in which having multiple areas of formal credentialing does *not* pose an identity problem, many engineers today, in addition to obtaining a degree in engineering, also have a law degree or a master of business administration. The market for such individuals is competitive, and the value placed on such combinations of credentials is quite high.

On the other hand, if one has a double major in computer science and fine arts, with another degree in journalism and a minor in French, it becomes difficult to attach an identity to this individual. Although identities can be either very useful or very problematic, they do in fact exist, and careful thought needs to be given to them during one's formal postsecondary education.

At the end of the day, you simply need to recognize that we live in a world where problems to be solved increasingly involve collaboration among multiple disciplines. The better equipped you are to function in that world, the more successful you likely will be.

13.3 Characteristics of Successful Teams

Turning now to the very practical topic of actually developing and working in teams, I apply the word "team" to describe collaborations ranging from a few scholars working together on a small project to large, multi-institution, multidisciplinary, and even multinational centers involving dozens to hundreds of researchers. Most of the points made below apply across this entire spectrum, though appropriately modified when the number of collaborators is relatively small.

The most obvious question to ask regarding working in teams is the following: What makes for a successful team? This is important if you want to create and manage a team as well as consider being part of one. Of course, the answer depends to some extent upon how one defines success, so let us assume

that success relates to outcomes that reflect achievement of project goals via a productive and collegial working environment for team members.

First and foremost, successful teams need an effective leader. Leadership is a somewhat elusive concept for many people as it tends to suggest someone being in charge, making all of the decisions, or having a specific title or role. Although true, leadership involves much more. First and foremost, a true leader understands and empowers others. When you are a true leader, your work no longer focuses exclusively on your individual success, but rather also on helping others succeed, including members of a collaborative team.

Additionally, the leader clarifies goals, helps build trust among those involved, creates a comfortable, safe, and productive work environment that ensures all views are encouraged and welcome, and then manages this environment effectively, providing resources and removing barriers so those involved can do their work effectively. I have seen teams of exceptional, willing, and able scholars literally fall apart owing to the *absence* of leadership, and teams of people who are marginally interested at the outset come together and do great things *because* of great leadership. Numerous excellent resources exist on the topic of leadership, and I find the following to be particularly valuable (Heifetz 1998; Heifetz, Grashow, and Linsky 2009; Heifetz and Linsky 2017).

The second characteristic of a successful team is diversity, inclusion, and belonging. Though we hear the term "diversity" used frequently and in many contexts, here it means involving individuals on a team who are different from one another—in every way you might imagine. Views, approaches to tackling problems, race, ethnicity, sex, gender identity, religion, nationality, birthplace, military service, age, and academic discipline. Building a diverse team—even if within a single discipline—weaves a tapestry of richness into the entire scholarly process of creating and disseminating new knowledge, yielding innumerable benefits. Yet, it does not stop with diversity. Those on the team need to be included, which is the job not only of the leader but of everyone on the team. All voices are important, all views should be welcome. And, being made not only to *feel* as though one belongs, but actually *does* belong by virtue of active engagement and respect, is foundational to each and every team.

The third characteristic of a successful team is the development and clear understanding, by all participants, of a shared vision for the work to be done, along with a clear sense of each individual's role in it. In my own experience, I have explained this as analogous to the rays of light passing through a lens and converging on the focal point (figure 13.3). Each ray represents a project participant and the lens the project framework that brings participants together such that they contribute to the project goal (focal point) while seeing their own

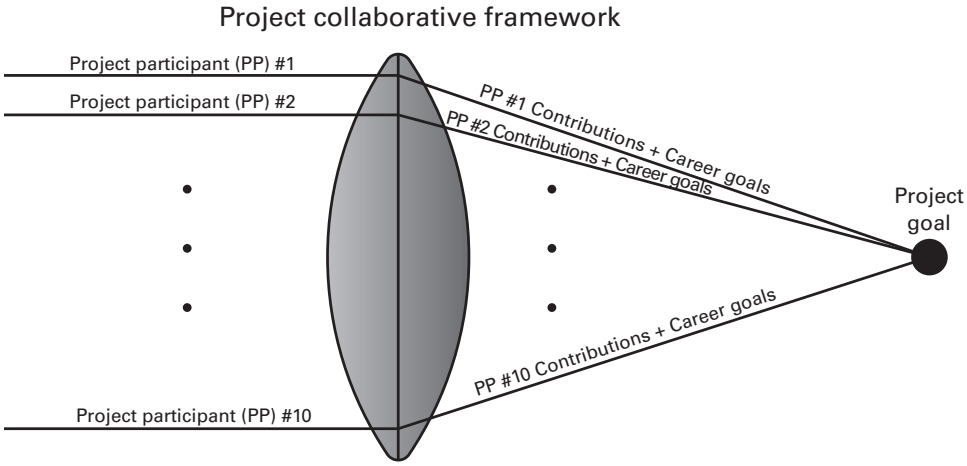

Figure 13.3
Conceptual depiction showing how the framework of a collaborative project (lens) allows individual project participants (rays) to contribute to the project goal (focal point) while simultaneously advancing their own career goals. For simplicity, only a few rays are shown converging on the project goal whereas, in reality, all do.

careers and interests advance in the process. I'll touch on this point a bit more in the next section, where we examine constructing a team.

The fourth characteristic of a successful team, and one which develops over time but must explicitly be pursued, is trust. Expecting you to devote a portion of your time to a project involving others means putting a part of your career in their hands. It also means giving up some of the power or authority you would have if you managed a project or pursued activities on your own. The reverse of course is true for others if you are leading a team. Trust arises via building relationships and ensuring a work environment that promotes open, frank and collegial discussion and welcomes dissenting views. Trust also comes about via the sharing of ideas, no matter how unconventional they may seem initially, and via a collaborative approach to achieving consensus on important decisions. Trust, mutual respect, and effective, open communication go hand in hand and are foundational to successful collaborative endeavors.

The fifth characteristic of a successful team, and one that often is the most difficult to achieve, is developing an appreciation and understanding of the terminology and methodologies used by others, especially if they are from academic disciplines different than your own. Initially, this can be frustrating because terms you have used without thinking likely have an entirely different meaning to others. I experienced this firsthand as a meteorologist when I began working with social scientists. You see, I use computer models of the

atmosphere to study severe storms, yet the word "model" meant something entirely different to my colleague social scientists.

Specifically, in the context of our work, to my social science colleagues "model" meant a theoretical framework for testing a specific hypothesis. Not a computer code. Not a bunch of equations to be solved. But rather, a conceptual framework. Although we struggled at first and even became frustrated because such a simple notion created a significant barrier to regular conversation about our topic, we soon learned to communicate effectively and, in the process, learned a great deal from one another about our own approaches and thought processes.

The sixth characteristic of a successful team is an agreed upon approach for assigning credit and recognition, including the following: authorship of papers and the ordering of authors; involvement in promotional and public relations materials as well as press releases, interviews, and media inquiries; quantification of involvement for the purposes of intellectual property disposition (chapter 12); and strategies for resolving disagreements or disputes should they occur.

The seventh characteristic of a successful team, and the role of the team leader, involves developing leaders. Although the team may consist of individuals across many career stages, each is on their own pathway or trajectory of professional growth. As the leader, you have the daunting but exhilarating responsibility of developing the capabilities of others, empowering, challenging, and resourcing them to grow in the many and often unique ways that are possible when working in teams. Learn about their career goals and ambitions and make sure the project is advancing them. Never treat project participants as "worker bees," and make certain everyone—from undergraduate student to senior researcher—understands the purpose and goals of the project and their unique contributions to it.

Finally, and most importantly in my view, you must *have fun* when working with other people! You may not particularly like everyone, but I am quite certain you can have a genuine appreciation for their work and the contributions they make to the project. Remember, a bright light at the focal point of the lens requires all of the individual rays to do their part while not interfering destructively with other rays!

13.4 Developing Teams and Engaging Boundary-Spanning Problems

Having laid the foundation regarding the characteristics of successful collaborative research teams, the obvious and most important requirement moving forward is to have a research problem that requires a team approach. That is, the problem should be of such a nature that it lies beyond the capabilities or

scope of an individual researcher and his or her research group, or requires expertise from more than a single discipline or type of organization.

Quite often, the problem to be tackled is identified by one or more people, but ideally and optimally, one person—one person—steps forward to actually lead the effort, both intellectually—as the visionary and subject matter expert—and administratively. And I want to stress that the leader must actually embrace all of the challenges as well as opportunities that come with team-oriented research. This includes addressing all of the items noted in the preceding section that make for successful teams. But it also includes the fact that teams consist of diverse individuals representing different ages, institutions, stages in career, races, nationalities, ethnicities, gender identities, cultures, and religions. Managing a group with such diversity can be challenging, yet it is precisely this diversity that brings multiple perspectives that are of such great value to team-based collaboration.

Given the tremendous value of collaborative research, numerous resources have been developed for creating collaborations and building teams (including those with international partners, as noted below, though with due consideration given to issues of research security, as discussed in section 10.3). One example is the National Science Foundation's Research Coordination Networks (RCN) program (http://nsf.gov/pubs/2015/nsf15527/nsf15527.htm), the goal of which is to "advance a field or create new directions in research or education by supporting groups of investigators to communicate and coordinate their research, training and educational activities across disciplinary, organizational, geographic and international boundaries. The RCN program provides opportunities to foster new collaborations, including international partnerships, and address interdisciplinary topics. Innovative ideas for implementing novel networking strategies, collaborative technologies, training, broadening participation, and development of community standards for data and meta-data are especially encouraged. RCN awards are not meant to support existing networks; nor are they meant to support the activities of established collaborations." Note the focus on both domestic and international teams, and that the program supports both large and small teams. Similar examples exist in other federal agencies, not only in the sciences, but also in the arts, fine arts, and humanities.

When building the research team, a number of important points must be considered. A potential team member must have the appropriate expertise and be interested in the project. In recruiting team members, it is the responsibility of the leader to articulate how a particular individual's capabilities fit the project, and how their expertise will contribute to the overall goal. You may wonder how this is possible for teams involving several disciplines, but such is the

unique role of the visionary leader. That is, the leader may not be able to fully articulate all details of each person's role at the outset, but he or she can provide each participant with a general idea of their role and excite them about the innovative nature of the project. As the project proceeds, each participant gains deeper understanding of their role, eventually becoming the expert in explaining it to others, including the leader!

Numerous funding opportunities, especially within federal grant agencies, exist to pursue team-oriented research, largely in science and engineering. NSF, NIH, and DOE—to name a few—all offer funding for major ($5 million or more per year) research centers, institutes, and regional hubs. Some are focused on specific topics, such as artificial intelligence and quantum computing, while others allow researchers to pitch their own ideas. Examples are shown below.

- National Science Foundation
  - Big Data Regional Innovation Hubs
  - Centers for Chemical Innovation
  - Engineering Research Centers
  - I-Corps Hubs
  - Industry/University Cooperative Research Centers
  - Major Research Equipment and Facilities Construction Program
  - Major Research Instrumentation Program
  - Materials Research Science and Engineering Centers
  - Mid-Scale Research Infrastructure Program
  - Nanoscale Science and Engineering Centers
  - National Artificial Intelligence Research Institutes
  - Physics Frontier Centers
  - Regional Innovations Engines Program
  - Science and Technology Centers
- National Institutes of Health
  - Centers of Biomedical Research Excellence
  - Clinical and Translational Science Award
  - IDeA Networks of Biomedical Research Excellence
  - P30 Center Core Grants
  - P50 Specialized Centers
- US Department of Energy
  - Energy Frontier Research Centers
  - Energy Innovation Hubs
  - National Quantum Information Science Research Centers
  - Regional Clean Hydrogen Hubs

Although NEH and NEA generally do not offer funding programs to create centers for scholarly activity, NEH operates a residential National Humanities Center (http://neh.gov/divisions/research/fellowship/national-humanities-center) "for advanced study in art history, classics, history, languages and literature, musicology, philosophy, and other fields of the humanities." NEA supports state and regional organizations and alliances that fund projects in the arts and fine arts.

Many opportunities also exist for large training and equipment grants, mostly in the areas of scientific research. Increasingly, regional research hubs are being funded to place additional focus on economic development and community transformation in the form of job creation, and on reskilling and upskilling, especially within economically disadvantaged communities. Multiagency federal programs, such as the Established Program to Stimulate Competitive Research (EPSCoR; sections 2.3 and 3.3), bring together multiple disciplines across several institutions within a given state/jurisdiction to address major research challenges and enhance competitiveness.

International collaborations, large and small, have been and continue to be vitally important to advance the progress of scholarship in all disciplines, from high energy physics and meteorology to art, drama, and musical theater. The development of major facilities is very much an international or multinational endeavor owing to their enormous cost and broad international user base. Examples include the Large Hadron Collider (http://home.cern/science/accelerators/large-hadron-collider) in Switzerland, the Atacama Large Millimeter Array (http://www.almaobservatory.org) telescope in Chile, and the Event Horizon Telescope (http://eventhorizontelescope.org), the last of which is a series of radio telescopes around the world that were brought together in a major collaboration that gave the world its first image of a black hole shadow. International collaborations and partnerships not only advance scholarly activities but they also promote international relations, cultural understanding, diversity, and serve as tools of diplomacy.

Yet, working in teams is not for everyone, and thus attention needs to be given to attitude and interpersonal skills when selecting team members. Team members need to enjoy working with others and be willing to share credit and assume a greater workload when health or other challenges take team members out of the game. They must be openminded and willing to learn from others and to try unfamiliar approaches. Bias and prejudice (chapter 8), if manifest as behavior, are absolutely toxic to research teams, as are people who tend to build alliances within the team to gain advantage over others. Frequently, it is difficult to know how someone who has *not* participated in team research will behave until they actually *join* a team. This is why significant

attention needs to be paid to creating an environment for the project that encourages open dialogue and the sharing of issues and concerns, so they do not become problems.

In executing the project once the team has been assembled, careful attention needs to be given to developing the shared vision and goals, and to identifying the roles and responsibilities of all team members. In especially large projects, such as multi-institution and/or multisector centers, an overall project manager, different from the project leader, may be given the responsibility of ensuring effective communication of all members by holding regular meetings, or video conference sessions if the team is geographically distributed. Small group sessions built around subthemes of the project often are helpful, and if the project is divided into thrusts largely involving single disciplines, it is important that cross-cutting activities be created to ensure that the various strands of disciplinary work eventually flow together.

Social and team-building activities, which can be done both within and outside the work environment, are especially valuable for building relationships and trust, though care must be taken to ensure all team members are able to participate. That is, if some on the team do not drink alcohol, for example, activities not involving alcohol should be offered. An example where team building proves valuable is a situation in which new ideas arise as the project proceeds and the team needs to decide how to respond. Good teams are able to redirect resources to pursue them, if deemed appropriate, without harming overall core goals.

I have had the privilege of leading research teams involving multiple disciplines and institutions for nearly four decades. In some cases, the team consisted of more than one hundred people from nearly a dozen different institutions. I also have been a participant in small team collaborations. Although leading teams and working in them certainly requires more effort than for other types of projects, the team research with which I have been involved provided the most intellectually exhilarating and rewarding experiences of my career.

13.5 Multisector Collaborations and Academic-Corporate Partnerships

Lest you have the impression collaborations of various flavors exist only among colleagues in academia, such is far from the case. Indeed, collaborations and partnerships—formal and informal, large and small, national and international—occur across all sectors of the research enterprise and involve academia, government, private industry, nonprofit companies, and other nongovernmental organizations. Activities range from significant corporate

engagement in large research centers and institutes to individual academic scholars working with their counterparts in the private sector. Even federal agencies partner with one another, and with the private sector, on a variety of programs to enhance America's research and education enterprise.

Early in my professional career, I learned that the word "partnership" has a very specific legal meaning, such as in a limited liability partnership or public-private partnership. Consequently, I was counseled to be mindful of the situation in which the word was being applied. In academia, the words "partnership" and "collaboration" often are used interchangeably and somewhat loosely, and I will follow that practice here. However, if you find yourself in a situation of uncertainty about which term is most appropriate, I encourage you to obtain legal guidance.

With that preface, let us begin by asking obvious and important questions: What motivates the creation of partnerships between academia and other sectors, especially private industry, and what forms do they take? Recall some of the expectations placed by society on today's academic institutions, as enumerated by Hill (2012, slide 15) and described in section 12.1: "a generator of new technologies; a prime source of new ideas; a founder of new companies; a solver of practical problems; a partner in economic development; a bridge to the world; a venue for political presentation; a critical contributor to economic growth; and a source of specialist leadership." Although research is a foundation of many postsecondary institutions, most of the items listed above are recent developments related directly to academic-corporate partnerships.

To answer our questions, consider the fundamentals of private companies: what they are, why they exist, how they operate, what they need to be successful, and how their foundational characteristics align with those of the academic research enterprise. Because space does not allow for a comprehensive treatment of all types of partnerships, I focus here on those between academic institutions and for-profit private companies.

The fundamental purpose of private for-profit companies is to provide various goods and services of value to society as a means for profit (understanding and appreciating the profit motive is important when creating academic-corporate partnerships, as described below). Companies innovate and are driven by a free-market economy to build wealth. If successful, companies remain in business, expand, redefine themselves over time, merge, and are acquired. To achieve this success, apart from the value of specific offerings, companies need, first and foremost, a capable and reliable workforce. They also need capital, space and facilities, raw materials in the case of manufacturing, effective marketing strategies, and new approaches, technologies, and products to remain competitive. Additionally, companies seek tax and other

incentives to identify optimal siting, are proponents of corporate-friendly policies and laws to lower costs and maximize profits, and often locate in communities having convenient transportation infrastructure (especially airports), high quality of life for employees, appropriate housing, and opportunities for expansion.

Turning now to colleges and universities, their fundamental purpose (sections 12.1 and 14.3) is to educate individuals as a public and private good, serve as a codifier of and repository for knowledge and understanding, and in the case of institutions performing research, generate and disseminate new knowledge. They also provide a community for personal and professional growth, serve as a space for thoughtful debate, and help prepare individuals to productively participate in and serve society.

What do such institutions need to be successful? First and foremost, jobs for their graduates. Indeed, academia plays a significant role in providing workforce to private companies, not only in terms of individuals who receive formal degrees, but also in the skilled technical workforce created by career and vocational technical schools, as well as via certificates and badges offered by institutions of higher learning and other organizations (e.g., in cyber security, information technology, data analytics). The provision of workforce does not require any sort of formal relationship between industry and academia owing to the fact that, at least for public institutions, corporate tax dollars fund some portion of higher education. Thus, apart from the salaries of individuals hired, companies need make no formal investment in an institution in order to benefit from the students it educates.

Colleges and universities also require internships and service learning opportunities for their students, funding for research and pathways toward practical uses for its outcomes, philanthropic support, and the ability to show a clear return on investment to a wide array of stakeholders including governing boards, parents, students, and lawmakers.

Historically, research interactions between academia and the private sector have been structured around individual projects (including federally funded centers), motivated by mutual need and value and framed by a supplier-consumer model. In this model, private industry, the principal consumer, provides funding to academic institutions to undertake research and development projects of specific interest to the company, or agrees to participate as a team member in a research center or consortium. In a manner similar to funding provided by federal agencies to support academic research (chapters 2 and 6), funding provided by private industry typically supports personnel (faculty, graduate student, and postdoctoral scholar salaries and fringe benefits), equipment, travel, and possibly publication costs (if industry is a partner in a center, their

support may not involve direct funding but rather be provided in-kind; e.g., use of corporate facilities or donation of personnel time for collaboration).

In return, private industry obtains access to the associated research outcomes and intellectual property (chapter 12). In many cases, students working on private sector-funded research later are hired by the supporting company because of their familiarity with company activities, and because of their proven capabilities (which both reduces risk on the part of the company and spin-up time for a new employee).

In many cases, research relationships between industry and academia, though having humble beginnings, blossom into partnerships bearing all manner of fruit. For example, many academic institutions now have research campuses, research parks, or corporate parks where private companies can establish facilities. This allows the company and institution to interact in a deeper, more continuous manner, sometimes leading companies to co-brand their products and services with their academic landlord.

Although academic-corporate partnerships increasingly are important in today's research enterprise, they can be challenging to establish and manage because, as noted above, private companies and academic institutions were created for entirely different purposes and thus operate with different philosophies, structures, and vocabularies. One of the biggest barriers to academic-corporate partnerships is intellectual property (IP; chapter 12) and the extensive legal and other negotiations that occur regarding ownership, rights of usage, and confidentiality. For institutions unfamiliar with or lacking the resources to engage in such negotiations, IP can be an insurmountable brick wall. Misperceptions by academia and industry about how each other operates (e.g., Council on Governmental Relations 2022), and their perceived lack of willingness and ability to work together, especially regarding IP, also hamper partnership creation.

A second challenge to academic-corporate partnerships involves managing conflicts of interest (chapters 9 and 10), especially in the context of graduate students and postdoctoral scholars working on projects funded by private industry. Importantly, such work must be performed without any undue influence by the private company sponsor, and conflicts of interest must be managed effectively (for example, if the faculty member overseeing a project owns stock in the company funding the work). If the company funding the work is in fact *owned* by the faculty member or their family, as often occurs in federal STTR and SBIR awards (sections 2.3 and 12.4), and if this same faculty member is the advisor of the students working on the project, care must be taken to ensure that the students' work is directly related to the project and that the faculty member is not utilizing them for other activities that benefit the company.

Third, most private companies understandably want to specify a set of deliverables for academic research projects they fund, using the contract rather than grant funding vehicle (section 2.3). Although some colleges and universities are willing to accept deliverables and thus "guarantee" their completion, most are not. This is because academic research is focused, in some cases with legal implications, on delivering "best effort," without the ability to guarantee outcomes.

Finally, as noted in section 13.1, it is important for researchers and academic institutions to not view private companies as banks, but rather as organizations that make decisions principally to ensure their profitability. This especially comes into play when colleges and universities seek to increase their research portfolios—in some cases dramatically so (e.g., genuinely doubling expenditures in five years)—which leads them to sometimes unrealistically view private companies as an avenue for significant funding solely in light of the uncertain and highly competitive nature of federal funding (section 2.1 and chapter 14). Private companies indeed can be excellent partners, but they always should be approached with the true spirit of a partnership in mind.

13.6 Establishing an Academic-Corporate Partnership

I have been fortunate to participate in many academic-corporate partnerships, starting from my first days as a university faculty member. Not surprisingly, I found that no single recipe or set of steps exists for creating them or guaranteeing their success because the factors involved are many and complex: discipline(s) involved, nature and size of the company, type of work to be performed, availability of students and other researchers to perform the work, personalities of all involved, philosophy of the participating academic institutions regarding corporate-sponsored research and mechanisms available to support it, local and state laws, and economic conditions. Imagine how this complexity increases if multiple companies are involved, say in a consortium associated with a major academic research center!

Consequently, I provide here four foundational principles for academic-corporate partnerships, along with a personal example of how modest initial interactions with private industry can blossom into major partnerships. Also, I wish to note that America is blessed with several excellent organizations that focus on the philosophy, creation, nurturing, and expansion of academic-corporate partnerships. They include the University-Industry Demonstration Partnership (UIDP), Government-University-Industry Research Roundtable (GUIRR), Association of Public and Land-grant Universities (APLU) Commission on Economic and Community Engagement, and several Association

of American Universities (AAU) programs on technology transfer and intellectual property.

The first of the four foundational principles is *mutual need*. In a partnership, individuals or organizations come together because they need one another and cannot achieve their desired goals alone. Although this may appear self-serving, and in some sense is, partnerships should yield *mutual benefits*, which is the second point. However, the benefits need not be distributed equally among all players, though all involved should see value for them or their organization as well as for other participants. Third, as noted previously, partnerships are built upon *mutual trust*. Without it, partnerships simply cannot thrive and, in many cases, dissolve. Finally, *effective leadership and management* are needed to ensure partnership success. I have seen many partnerships begin with great possibility and excitement, only to see them wither on the vine owing to the lack of effective stewardship.

With those points in mind, my first taste of interacting with private industry came one year after becoming a university professor. Specifically, I received an NSF Presidential Young Investigator (PYI) award, which provided $25,000 per year for five years, and another $37,500 in matching support per year if I were able to obtain $37,500 per year from other sources, such as private industry. Given that my research involved computer simulations of thunderstorms, I reached out to several private computer manufacturers as obvious partners. In so doing, I quickly learned that I needed to express my work in general terms (which wasn't that difficult because everyone experiences weather and has their favorite weather story to share), describe how it related to the company, and enumerate how the company might benefit by supporting me. Because NSF provided matching funds, the argument of leveraging corporate funding against federal funding was quite compelling to potential partners and remains so today. I note that, at the time, my university had no corporate engagement office or intellectual property support structure, so I simply struck out on my own. I return to that point below.

A year later, I began writing a proposal with a very esteemed colleague to establish a research center focused on predicting individual thunderstorms with computer models—something most people, and prevailing theory, said was impossible. Ironically, the proposal not only built upon my PYI work (and of course the pioneering work of my senior colleague), but also required the engagement of corporate partners that, fortuitously, turned out to be exactly the ones with which I had built a working relationship two years earlier! To our great surprise, our proposal was one of eleven funded out of 323 submissions; and thus, in 1989 NSF established the Science and Technology Center for Analysis and Prediction of Storms (CAPS).

As our work began to show evidence of success, I reached out to the manager of weather services at American Airlines (AA), whom I met by virtue of my work in aviation weather, and also owing to funding my university was receiving from the Federal Aviation Administration. With his strong support, I was able to convince AA's executive vice president, and ultimately its chairman, Robert Crandall, that our novel CAPS weather technology could potentially provide value to AA's hub operations in Dallas, Texas and thus throughout its system. Project Hub-CAPS was born.

That three-year effort brought $1 million to my university, along with the first research supercomputer in the state. Based upon the difficulty faced in negotiating terms of an agreement with AA, this project also spurred the creation in my university of an intellectual property office. In addition, AA endowed a professorship in my home department—which certainly was not an initial goal or expectation but reflected the reality of a genuine, successful partnership.

As Hub-CAPS was winding down, AA expressed a desire to continue using its products for actual operations. Because such capability is beyond the scope of a research university, I decided to launch a private company—which was an expectation, or at least a hope, for NSF centers such as CAPS. I thus cofounded Weather Decision Technologies (eventually acquired by DTN), and it assumed responsibility for providing operational products to AA. In so doing, it obtained an exclusive IP license (chapter 12) to the CAPS technology and also funded continuing research associated with it at my university.

Around that same time, a major energy company—Williams Energy Marketing and Trading—expressed interest in our ever-maturing weather prediction technology, and thus I approached them, through a student at my university who was one of their key employees, about a possible partnership. A year and eleven contracts later, the $10.6 million partnership was consummated. It was showing notable success when the Enron scandal brought down the entire energy marketing and trading enterprise, thus shuttering the project. However, the Williams Companies funded an endowed chair in my home department and contributed significantly to establishing a supercomputing center at my institution.

I wish to note that, in establishing both the Hub-CAPS and Williams projects, then University of Oklahoma president and former US senator David L. Boren was instrumental by virtue of his strong support and personal and professional interactions with both AA and Williams.

Two other major projects, one involving significant corporate engagement, emerged from CAPS and its associated activities: The NSF Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere and the NSF Large Information Technology Research project titled Linked

Environments for Atmospheric Discovery. More detail about how these and other activities emerged from CAPS can be found in an article prepared by NSF (National Science Foundation 2013a).

In reflecting upon these strongly connected events—which are not unique in the world of academic-corporate partnerships—I continue to be amazed at how one phone call, one introduction, can lead to a cascade of successes that transform institutions and establish careers.

With those examples as a hopefully motivating force, I suggest you do the following if you wish to explore creating a collaboration or partnership with a private company, being sure your institution is aware of your activities. First, learn as much as you can about the company and define very specifically the value they might obtain by working with you. Second, formulate a research plan and learn how to describe it to both expert and general audiences (chapter 11) because eventually, your idea will be pitched, by you or someone within the company, to senior corporate leaders who likely will not be deep subject matter experts.

Third, recognize that, in most cases, your first contact with a company will be someone you know, or at least someone who is familiar with your work. Their preexisting relationship with you, mutual colleagues, or even your institution (e.g., if they or their relatives are alumni) is helpful in "breaking the ice" for next steps. In the absence of these relationships, do not be shy about "cold calling" the company to introduce yourself and determine how to best begin engaging them. Some companies have specific mechanisms for external engagement, but many do not. You should not be discouraged if your initial overtures fail to gain traction. However, the most important thing to remember is to go in prepared!

Fourth, if you reach the point of making a formal pitch to the company or preparing a written proposal, do not approach those activities as if you were dealing with a federal funding agency. Although details of the proposed research obviously are important and must be addressed, a company's greatest interest usually lies in how the work will translate into profit—either through enhancement of existing corporate activities or the creation of new ones. Coordinate with your corporate contacts to ensure you are addressing issues of direct relevance to the company and are "speaking their language," rather than the language of an academic scholar.

Finally, many academic research institutions house sponsored programs and corporate engagement offices to assist you. However, many do not, and this especially is true for ERIs and MSIs. If you find yourself in this situation, contact your advisor or senior research officer for advice. Also, contact the aforementioned national organizations, which can provide wise counsel. You should be encouraged by the fact that, as noted in section 12.3, federal agencies now

are working to provide administrative infrastructure support to academic institutions for proposal development, project execution, intellectual property disposition, and corporate engagement, in addition to funding for research. In so doing, those institutions that historically have not been able to participate in academic-corporate partnerships now will be empowered to do so.

13.7 Beyond Research in Academic-Corporate Partnerships

While serving as Oklahoma Cabinet Secretary of Science and Technology, and based upon my personal experiences as a researcher, private company cofounder, participant in many projects with industry, and university vice president for research, I developed a framework for academic-corporate partnerships founded not upon a consumer-supplier model, but rather on a peer-to-peer partnership model in which academia and industry interact at deeper, broader levels and leverage their strengths and differences for maximum mutual benefit. The need for a broader approach was stimulated by the fact that many companies do not wish to enter into sponsored research agreements with academic institutions which, as noted previously, can be complex and difficult to create. Additionally, companies often do not wish to license existing intellectual property or work jointly to develop new capabilities. Rather, they want access to other resources provided by colleges and universities. Most of the elements of the framework are activities already underway at many colleges and universities, and my strategy was to organize and make them more visible and readily available.

A final motivation for the new framework is the fact that, during the past few decades, the percentage of R&D funding provided to academic institutions by private industry (figure 2.5) has been nearly constant. Although funding is a single, imperfect measure of partnerships (additional ones are presented in chapter 14), these data suggest that industry is not taking full advantage of the extraordinary capabilities and assets of America's colleges and universities, and conversely, academic institutions are not reaping the full benefits of partnering with the private sector. My multicomponent framework is designed to help address this issue.

Because space does not allow a full description of all aspects of the framework, I summarize here a few of them.

- **Consulting:** Private companies frequently need access to subject matter experts in a variety of disciplines, and most colleges and universities allow their faculty to consult for a certain percentage of their time. The company benefits by obtaining needed expertise, and this especially is

true for small and medium sized businesses, which have relatively few personnel and cannot afford to hire experts in every area of need. The faculty member benefits not only financially, but also by gaining experience and perspectives beyond academia to enhance their own teaching and research. As a result, students benefit as well.

To promote this concept, academic institutions can seek volunteer faculty consultants from across the institution and advertise their capabilities broadly, thereby heightening institutional visibility and its service to society. Additionally, the funding to consultants can be routed through the academic institution, thereby removing the burden of faculty having to develop their own consulting companies and ensuring legal use of institutional facilities, as necessary. Finally, consulting, even if performed at a small level, serves to begin building a relationship between the sponsoring company and the academic institution, leading to enhanced trust with time and possibly larger projects in the future.

- **Data sets and data analysis:** Data, and sophisticated analyses of them, are the coin of the realm in today's knowledge economy. From online shopping patterns to medical diagnoses to legal analyses to understanding and predicting the behavior of competitors, the mountains of data being collected and analyzed today are improving efficiencies and enabling entirely new industries. Academic institutions not only are repositories of historical data and knowledge in their libraries, now rapidly being digitized, but also are home to sophisticated techniques for synthesizing, fusing, and assimilating vast types and quantities of data for a virtually unlimited array of uses.

  In this component of the partnership framework, private companies engage with colleges and universities to use extant data held by the institution, analyze proprietary data owned by the company, collect new data that is of interest to the company, and assist in developing algorithms for use by the company. Such activities could be performed by faculty, as consultants (see above), or by undergraduate or graduate students as a component of, or a supplement to, their formal educational activities. The sponsoring company benefits in obvious ways (e.g., streamlining operations, improved understanding of customer needs, more efficient supply chains, market differentiation factors), and the experiences gained by faculty and students working with real data, in real corporate settings, likewise is extremely valuable.

- **Facilities and equipment:** Many academic institutions are blessed with a wide array of facilities and equipment for conducting research, ranging from clean rooms, wet laboratories, machine shops, greenhouses,

powerful microscopes, and specialized equipment such as lasers to theatrical production facilities and equipment. Many of these resources are notably expensive and sometimes unique. Although larger companies likewise have specialized equipment, typically at a scale much larger than what one finds in academia, small- and medium-sized businesses typically do not. More importantly, many small- and medium-sized businesses were not even created because such capabilities were beyond their budgetary constraints. Yet, small- and medium-sized businesses represent the majority of private sector revenue in the US.

This component of the framework involves private companies using academic facilities and equipment to enhance their commercial success and promote local economic development. Academic institutions can legally charge fees for such usage and involve students and faculty on associated projects to ensure educational benefit. Such interactions can be aligned with the strategic directions of the academic institution and company, and as in many of the components of this framework, such collaboration—even though perhaps not involving research at the beginning—can lead to deeper interactions in the future, including sponsored research, internships, and so on.

- **Internships/apprenticeships:** Internships and apprenticeships are an excellent and long-standing mechanism by which private companies engage with academic institutions to develop talent, bring corporate experience to the educational process, stimulate new ideas and ways of thinking within a company, and "test drive" potential future employees. Such programs benefit academic institutions by providing practical experience for their students, professional relationships, monetary support, and often a discriminating advantage when applying for positions.
- **Restricted funding opportunities:** Quite frequently, private companies wish to pursue grant/contract funding or other opportunities but cannot do so by themselves because the solicitation requires that a nonprofit or academic institution serve as the lead organization or "prime." Conversely, certain funding opportunities available only to academic institutions require the participation of private companies. Developing such relationships, as noted previously in this chapter, can be difficult, time consuming, and require years to mature. Yet, those having strong and long-standing academic-corporate partnerships tend to have a distinct advantage in such situations.

  This particular component of the framework highlights the importance of academic-corporate partnerships in research and creative activity in seeking external funding for mutual benefit. As noted above, the relationship

need not begin with research in mind, but rather can start with an internship, use of a data set or facility, or even a bit of consulting by faculty. The most important point is that researchers and their institutions should plan ahead and consider which types of partner-based funding opportunities (e.g., the NSF Engineering Research Center) they might wish to pursue. Initiating a partnership at the same time one decides to pursue an opportunity is not a useful strategy. This is because most peer evaluations (chapters 6 and 7) of academic-corporate interaction consider the nature and history of collaboration. If the period has been relatively brief, and compelling evidence of meaningful collaboration is lacking, reviewers likely will doubt the probability of success.

Finally, motivated by many of the challenges to multisector partnerships described in this chapter, the White House issued a report (President's Council of Advisors on Science and Technology 2021) outlining a possible new framework for future partnerships. Although the application area was industries of the futures (e.g., artificial intelligence, quantum computing, biotechnology), the structure is applicable to any set of problems involving multiple disciplines and sectors of the research enterprise.

Assess Your Comprehension

1. Compare and contrast the following types of scholarship: intradisciplinary, interdisciplinary, cross-disciplinary, and transdisciplinary.
2. What are the principal benefits of and drawbacks to collaboration?
3. What is "convergence" in the context of research and creative activity?
4. What principal factors motivate collaboration?
5. What key questions should you ask yourself if you are considering forming a collaborative team?
6. How have trends in collaborative research changed over the past several decades?
7. How and when did the current array of disciplines in academia come into existence?
8. What options exist today for obtaining formal credentialing in areas other than one's core discipline of study?
9. What barriers exist to collaboration involving more than one discipline? Consider researchers, funding sources, communication mechanisms, and other factors.

10. Why is having an identity as a scholar important even in a multidisciplinary world?
11. What are the key characteristics of a successful collaborative team?
12. Describe the importance of diversity, in the broadest interpretation of the word, in collaborative teams.
13. What characteristics are most important when considering individuals to join a collaborative team?
14. What resources exist to support the creation of collaborative teams and networks?
15. What actions can be taken to ensure the success of a collaborative team once it has been formed?
16. What can be problematic about the term "partnership" in the context of academic-corporate collaborations?
17. What are the fundamental characteristics of private companies and what do they need to be successful?
18. What are the fundamental characteristics of academic institutions and, in the context of research, what do they need to be successful?
19. Describe some key barriers to academic-corporate partnerships.
20. Why should academic institutions not consider private companies as banks in the context of research partnerships?
21. What are the four foundational principles of academic-corporate partnerships?
22. What steps should you take in preparing to develop a partnership with a private company?

Exercises to Deepen Your Understanding

Exercise 1: Some of the most complex and intellectually stimulating problems now are being tackled through the work of multidisciplinary teams. For this exercise, create the framework of a plan to study a large-scale societal issue. In doing so, however, you must take a multidisciplinary approach that assembles at least two different disciplines, one from the sciences and one from the arts (you may use more but these two are the minimum required). As you are creating your framework, here are a few things to consider:

- Why is the problem you chose important and what are the driving intellectual questions?

- What value exists in studying the problem?
- What disciplines will be involved and why did you choose them?
- What different perspectives does each discipline bring to the project?
- What challenges do you foresee in assembling individuals from these various backgrounds and perspectives together to function as a coherent team?

Exercise 2: Most federal agencies that fund research, and most academic institutions, are organized along traditional disciplinary lines yet strongly promote multidisciplinary research and creative activity. How would you go about reorganizing or otherwise modifying the structure of such institutions so they support strong discipline-based research as well as multidisciplinary activities? In the case of academia, where performance evaluations are strongly linked to individual achievement (e.g., number of papers published, proposals funded, students mentored), what changes would you suggest in order to adequately recognize and reward the work of teams? And how would you ensure that one discipline recognizes value and legitimacy in the engagement of another, given often strong differences in culture, even with regard to mechanisms for formally placing research outcomes in the scholarly archive?

Exercise 3: If you are a graduate student, postdoctoral scholar, or faculty member at any career stage, what actions might you take to maximize your ability to work on problems that span multiple disciplines, or pivot in your career to achieve the same end? For example, in the case of students, this might include taking courses, pursuing minors of areas of concentration, or obtaining certificates and badges outside your major discipline. Which areas would you choose, and why? In the case of postdoctoral scholars or faculty, this might include attending seminars and arranging for special mentoring, taking courses to broaden your expertise, or taking a sabbatical to gain knowledge in a discipline different from your own.

Exercise 4: How would you characterize your own research in the spectrum of unidisciplinary to transdisciplinary scholarship? If it leans more toward unidisciplinary, describe ways in which you could expand the scope of your research topic or expertise to include other disciplines and thereby tackle a broader range of problems. What value would be wrought in such expansion, both from an intellectual point of view as well as with regard to societal benefit? How would you go about creating such an expansion, and can you identify researchers today who you would invite to join you as collaborators?

Exercise 5: Diversity in scholarly activities is important for a wide array of reasons, as described in this chapter and throughout the book. How would you, as a leader, go about assembling a diverse team of collaborators to tackle an especially important and intellectually stimulating problem? What factors regarding diversity—in its broadest possible interpretation—would you consider, and what steps would you take to also ensure equity, inclusion, and a sense of belonging and participation?

Exercise 6: Identify one or more real for-profit private companies you could approach to develop a collaborative research partnership. Describe in detail why they are best suited for the partnership, the research you would propose to them, the manner in which they would collaborate with you (if appropriate), and the expected outcomes and benefits to both you and them. Discuss any previous or existing connections you have with the company and the manner in which you would utilize them in approaching the company. What specific issues or challenges might you expect to encounter? If your institution contains offices that support corporate engagement, involve them in the process and describe particular experiences, both positive and negative, that surprised you. If not, seek assistance from your advisor, your department chair, dean, or senior research officer regarding options to obtain such assistance externally.

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