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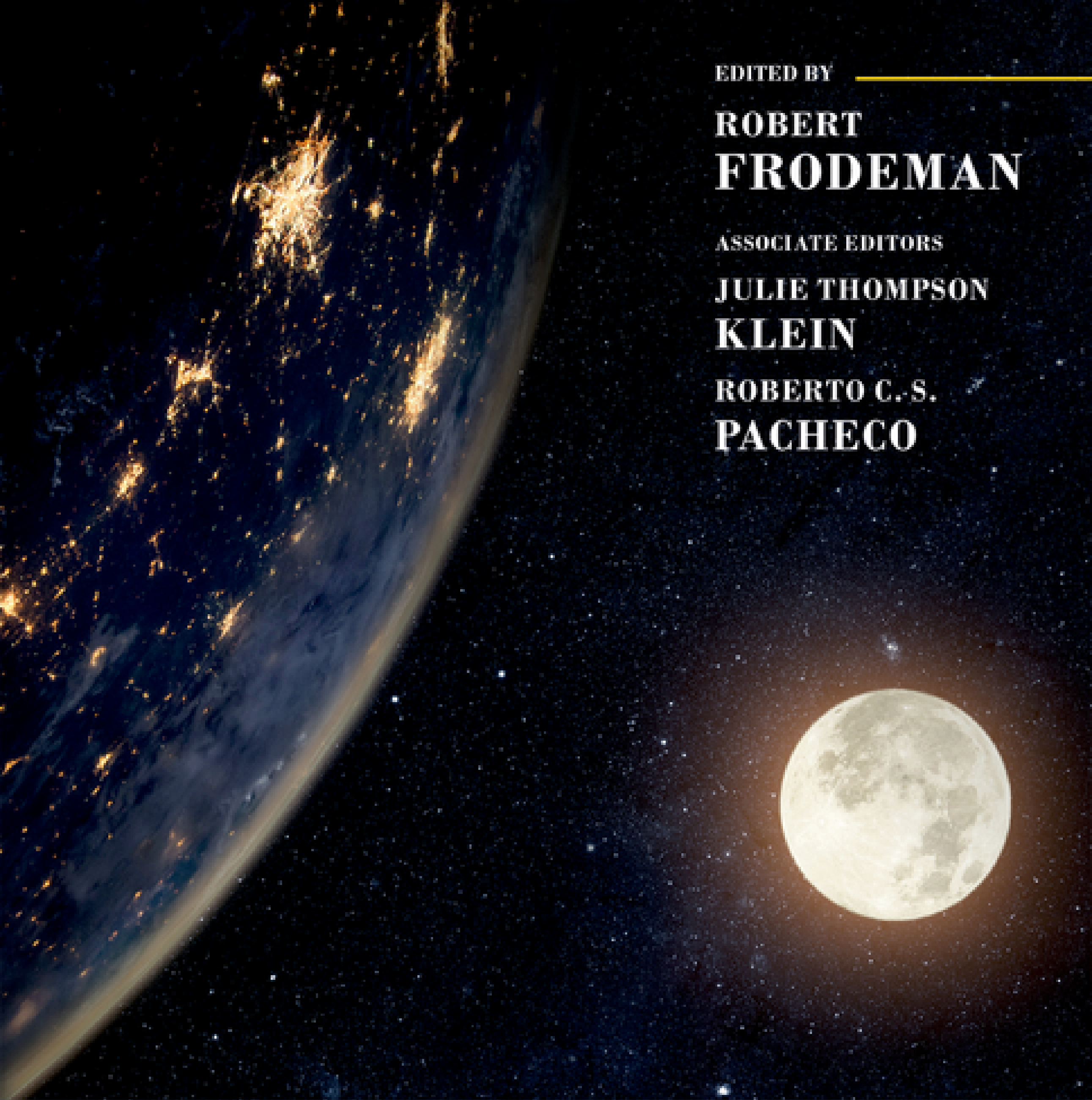

The Oxford Handbook *of* INTERDISCIPLINARITY

SECOND EDITION

THE OXFORD HANDBOOK OF

INTERDISCIPLINARITY

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Preface

The *Oxford Handbook of Interdisciplinarity* (HOI) has been 25 years in the making. By way of preface, it is useful to recount its history over the two editions, published in 2010 and 2017.

While the editors of the first edition had been involved in interdisciplinary research—and research into interdisciplinarity—for decades, their active collaboration dates from 2001. During the 2001–2002 academic year Chief Editor Robert Frodeman was Hennebach Visiting Professor in the Humanities at the Colorado School of Mines (CSM), where co-editor Mitcham was a professor within the Division of Liberal Arts and International Studies. Their common interests in interdisciplinarity led to creation of a project titled *New Directions in the Earth Sciences and the Humanities*, launched with seed money from CSM. Soon thereafter, they invited Julie Thompson Klein, then professor of humanities at Wayne State University, to join them.

New Directions launched formally in 2002, with the goal of conducting "experiments in interdisciplinarity." A call for proposals for teams to create projects at the intersection of the Earth sciences and the humanities focused on environmental questions relating to the theme of water. Of the 31 proposals, reviewers chose six for funding of $10,000 each, contingent on a 1:1 match. Over the next few years New Directions attracted several hundred thousand dollars of funding from a number of entities—most prominently the National Science Foundation (NSF), but also the National Endowment for the Humanities (NEH), National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA), Cooperative Institute for Research in Environmental Sciences (CIRES), National Center for Atmospheric Research (NCAR), Geological Survey of Canada (GSC), and Columbia University's Earth Institute and the Pennsylvania State University Rock Ethics Institute. The six teams also agreed to meet in workshops to exchange insights arising from their projects.

The first workshop took place in spring of 2002 near Tucson, Arizona, at Biosphere 2. The lessons recounted there highlighted the need for some type of summary account of interdisciplinary research. A second workshop at CSM in the fall of 2002 continued the case-based approach to interdisciplinarity by including a field trip to the nearby Rocky Flats nuclear weapons production facility. It also led to a special issue of the *CSM Quarterly* in 2003, an early effort to collect articles on theory and practice of interdisciplinarity. The effort to sort out lessons continued at a third workshop, hosted by Penn State in fall of 2003. When Frodeman relocated to the University of North Texas (UNT) in fall of 2004, New Directions expanded to encompass science, humanities, and policy. Funding from UNT made it possible to address a wider range of interests across fields including differences across types of interdisciplinarity and critical assessment of knowledge production.

With this rebranding, New Directions turned its focus to a series of larger, thematic workshops. The first, held in St. Petersburg, Russia, in summer of 2004, was focused on *Cities and Rivers: St. Petersburg and the Neva River*. Funded by the NSF, it examined challenges in addressing water quality and quantity. In the aftermath of Hurricane Katrina, in March of 2006 the NSF funding supported a workshop on *Cities and Rivers 2: New Orleans, the Mississippi Delta, and Katrina*, focused on the breakdown between knowledge producers and users that clearly contributed to the disaster. Subsequent workshops took place in spring of 2007 at NASA Ames (on environmental ethics and space policy) and in southern Chile (on challenges facing frontier ecosystems).

Accumulating lessons from the experiments led the organizers of New Directions to approach Oxford University Press (OUP) in 2006 about creating a handbook that would pull together disparate strands of insight concerning inter-and trans-disciplinarity. After acceptance of the prospectus, workshop meetings centered on efforts not simply to explore interdisciplinary in particular case studies and projects but also to take interdisciplinarity itself as a project. Links also expanded to Europe, including contact with the Network for Transdisciplinary Research (td-net) around the concept of transdisciplinarity. Related activities included a meeting with Peter Weingart and Wolfgang Krohn, hosted at the Center for Interdisciplinary Research (ZIF) in Bielefeld, Germany, in fall of 2006. This event also led to engagement with a leading group for study of interdisciplinarity in the United States, the Association for Interdisciplinary Studies.

Institutional support of New Directions at UNT increased by an order of magnitude in fall of 2008, when it was absorbed into the Center for the Study of Interdisciplinarity (CSID). The first edition of this handbook became a cornerstone of the CSID. The CSID's original purpose was to introduce a greater degree of order into the field of interdisciplinary research, education, and practice by creating a work that would become a basic reference for accounts of and future attempts at interdisciplinarity. Its scope was wide: encompassing historical accounts of attempts at interdisciplinarity, successes and failures within both research and education across domains and fields, and best practices for future explorations of interdisciplinarity. CSID was defunded and de-institutionalized by UNT in the fall of 2014, suffering the fate of many efforts at interdisciplinarity. Nonetheless, interdisciplinarity today takes place at an expanding number of sites, on multiple levels, and in multiple types and forms.

Seven years have passed between the first and this second edition. During this period, interdisciplinarity and transdisciplinarity have grown epistemically, geographically, and institutionally. This new volume, consisting of half new essays and half revised essays, has sought to respond to these developments. It is distinguished by the addition of Roberto Carlos dos Santos Pacheco to the editorial team. Replacing Mitcham, Pacheco is a professor in the Department of Knowledge Engineering, Federal University of Santa Catarina, Brazil. This second edition combines updated and new contents in all sections. In addition to topics such as smart cities, sustainability sciences, and new public services, this edition also includes contributions of authors from more regions, particularly South America, where interdisciplinarity has been institutionally included as a public policy to foster education, science, and technology. Together, the updates and additions of the 2017 version handbook further its original goal of providing a well-grounded understanding of interdisciplinarity across its many forms and themes.

Acknowledgments to the Second Edition

We offer our thanks to Oxford University Press: Ian Sherman of Oxford University Press first championed the idea of this volume at OUP, and Helen Eaton brought it fruition. Lucy Nash of OUP has sheparded this second volume to completion. We also acknowledge the work of Bratzo Balarin, editorial assistant at the University of North Texas, who proofread final versions of the chapters. Finally, Keith Wayne Brown deserves recognition for the central role he has played as managing editor for the second volume.

Robert Frodeman
Julie Thompson Klein
Roberto C. S. Pacheco

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Contributors

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PART I

THE LANDSCAPE OF KNOWLEDGE

CHAPTER 1

THE FUTURE OF INTERDISCIPLINARITY

An Introduction to the 2nd Edition

ROBERT FRODEMAN

> As a simple fact, interdisciplinarity responds to the failure of expertise to live up to its own hype.
>
> —Fuller and Collier 2004

It might seem odd to begin the *Oxford Handbook of Interdisciplinarity* with the question of whether interdisciplinarity has a future. For both individually and as a whole, the 46 chapters that follow illustrate the utility of the concept as well as its importance in prompting innovation in both research and pedagogy. On the other hand, some clarity concerning the goals of the field, as well as the overall goals of this book, would be helpful. I speak for myself rather than my fellow editors or authors; but given the fraught nature of conversations surrounding the term, the varied and even contradictory meanings assigned to it, and its sometimes function as an empty honorific, an exploration of the future prospects of interdisciplinarity seems worth some attention.

The issue is in part one of definition. But here we have to define definition. It could mean the demarcation of interdisciplinarity in comparison with its cognate terms—disciplinarity, multidisciplinarity, and transdisciplinarity—as well as the swarm of other phrases that pass in and out of usage (antidisciplinarity, meta- and infradisciplinarity, cross-disciplinarity, etc.). Julie Thompson Klein's chapter in this volume does an admirable job of making sense of these terms, and there is no point in replicating that effort. I have in mind something else: the way in which ambiguities in the meaning of key terms have functioned within the political economy of knowledge—and whether those ambiguities have now outlived their usefulness.

Several of the subsequent chapters touch on related themes. Carl Mitcham and Wang Nan's chapter examines the inter- and transdisciplinary nature of ethics (whereas the focus here is on the ethics and politics of interdisciplinarity). Anne Balsamo's chapter addresses the ethics of interdisciplinary research via an Aristotelian account of what she calls interdisciplinary

Frodeman, R., *The Future of Interdisciplinarity: An Introduction to the 2nd Edition.* In: *The Oxford Handbook of Interdisciplinarity, Second Edition.* Edited by Robert Frodeman, Julie Thompson Klein, and Roberto C. S. Pacheco: Oxford University Press (2017). DOI 10.1093/oxfordhb/9780198733522.013.1

shift work. Steve Fuller's chapter on the military-industrial stimulus to interdisciplinarity recognizes that we have been too ready to dismiss outside influences on the academy as neoliberal "interference." Michael O'Rourke's chapter reviews ongoing debates about the nature (or existence) of an interdisciplinary method. Playing off of these accounts, my focus is on what can be broadly called the rhetorical dimensions of interdisciplinarity.

Both "interdisciplinarity" and "transdisciplinarity" have functioned as boundary objects that have had different meanings at different times and for different groups. Interdisciplinarity is most commonly used as a portmanteau word for all more-than-disciplinary approaches to knowledge, with the overall implication of increased societal relevance. This is how it is used in the title of this volume, even though the term more specifically refers to the intra-academic integration of different types of disciplinary knowledge. Similarly, transdisciplinarity has often referred to Hegelian-like syntheses of all knowledge—again, an academic goal—although today it is more commonly used to designate knowledge that is coproduced, where academics work with nonacademic actors of one type or another. (This has also been called Mode 2 knowledge; see Gibbons et al. 1994.)

These ambiguities have served a strategic function. In both cases they have allowed academics to gesture toward conducting research that's more relevant than "normal" disciplinary knowledge, while avoiding the painful task of actually working with people outside the academy. If this sounds critical of the community of interdisciplinarians, it is a criticism that applies here as well as to others. In part, this failure is simply a matter of the *deformation professionnelle* that all academics are prone to: our tendency to get caught up in inside-baseball debates. But there is more at work here than that.

We should not romanticize the matter: Working with nonacademics can be arduous. In fact, the topic has an ancient pedigree: The question of public engagement, and its various difficulties, is a dominant theme of Plato's work. The fate of his mentor illustrates the dangers of public engagement—that is, of seeking to be relevant. In response to Socrates's judicial murder, Plato developed the dialogue form as a means for safely and artfully presenting controversial ideas. Plato, after all, never appears in the dialogues; his beliefs have to be sussed out from the exchanges between different speakers. His reliance on the dialogue form suggests that Plato believed that a philosophical rhetoric was as crucial to thinking as any particular epistemic account of things. It is through skillful rhetoric, after all, that ideas come alive within a community. Of course, "rhetoric" is usually taken as "manipulative speech"; but for Plato (and Aristotle) rhetoric was concerned with the question of how to make sure that audiences truly "get" what is at stake.

On this account, then, interdisciplinarity consists of not only the study of how to integrate various kinds of disciplinary knowledge—call this the epistemic task—but just as much the analysis of the challenges surrounding effective communication to different audiences—call this the political and rhetorical element. While exceptions abound, the latter has been neglected within accounts of interdisciplinarity (see, for instance, O'Rourke's description of his own toolbox project in chapter 20).

Beyond *deformation professionnelle*, the incentives and disincentives of academic culture have led interdisciplinarians away from philosophical rhetoric and toward a preoccupation with epistemology—or as it appears in the literature, "method." It is a case of disciplinary capture (Frodeman & Briggle 2016): Researchers on interdisciplinarity *mean* to increase the relevance of academic work, but over time the community becomes insular, and recreates the accoutrements of disciplinary culture—a recondite vocabulary, a canon, a closed group, conferences, and journals. Some movement in this direction is appropriate; but too much becomes what Fuller calls "epistemic rent-seeking." (While in her chapter for this volume Bammer argues that the disciplining of interdisciplinarity is precisely what is called for.)

The problem arises when the need for epistemic bona fides within one's own reference community overwhelms attention to the larger dimensions of interdisciplinarity. Rhetorical issues such as timeliness, an eye for the main point, and a commitment to the needs of a specific audience, while important to interdisciplinarians, lack the intellectual excitement of debates among the cognoscenti. Similarly, political questions, such as who speaks and who gets listened to, and how authority is distributed among the participants in a conversation, get marginalized. As a prominent interdisciplinarian once put it to me, while discussing whether policy makers and user groups should be involved in a conference on interdisciplinarity we were planning: "Nah—we'd have to dumb things down."

Policy makers are not dumber than academics; but they are less in tune with in-group epistemological niceties. Of course this (the dominant) approach to interdisciplinarity views itself as concerned with practical needs, but it does so via a tacit embrace of a disciplinary model of dissemination where insights are first worked out by experts. These insights then trickle down to the "lay" public without much (inter) active engagement. Abstract principles of a methodology are offered with less attention given to working things out on the fly, in *media res*. The implicit message is that the experts remain in charge. Put differently, interdisciplinarity has functioned at a distance from the field of policy studies, whose concerns are fundamentally rhetorical in nature, focused on the uptake of academic knowledge by the larger world. Put differently again, interdisciplinarians have a tendency to abandon their status as thinkers of the "in-between" and to join the ranks of the specialists.

Now, too much can be made of this contrast between method and rhetoric. Of course there is a "method" to one's rhetoric; otherwise it is just ad libbing. But in contrasting a focus on interdisciplinary method with the need for a philosophical rhetoric I want to highlight the importance of something closer to improvisational comedy or jazz. While the jazz musician comes armed with knowledge (of, e.g., chord progressions), the real business occurs while riffing with others. A rhetorically sensitive interdisciplinarity begins with the needs and perspective of a specific audience in a particular context, armed with a toolbox of approaches that can be tweaked as needed. This contrasts with a top-down, methodological attitude that develops a set of principles which are then programmatically applied to different situations (cf. Frodeman 2013). If done right, one's interlocutors sees no "method" at all.

But if these ambiguities have served multiple purposes and audiences—providing the appearance of responsiveness on the one side, professional legitimacy and the pleasures of tenure on the other—one wonders whether their usefulness may be coming to an end. We may have reached peak interdisciplinarity.

Treat this analogy advisedly, for just as with "peak oil," it may turn out to be an often predicted but never-quite-reached point of decline. Interdisciplinarity may yet become central to the transformation of the twenty-first-century university. Note, however, that people outside of universities already rely on a different vocabulary. Politicians and citizens speak of impact, or accountability, or relevance. It is worth asking what difference it will make if talk of "interdisciplinarity" shifts toward conversations centered on one or another of these terms—how it will affect the range of goals that universities are organized around, as well as who is in charge of the conversation.

In terms of remaining in charge, don't bet on the academics. The cluster of terms just mentioned already represents a countermovement that, while sharing some of the intuitions surrounding interdisciplinarity, has its own distinct imperatives. It is also backed by the power of the vote and the public purse. The changed landscape I speak of does not only mean the increasing influence of corporate models for the university. More fundamental—and less susceptible to shifts in political ideology—is the growing role of knowledge processes throughout society, driven by the ongoing revolution in information and communication technology. The result may have become a cliché—the "knowledge society"—but that does not make the point any less portentous.

These processes are leading to the displacement of the university from the center of knowledge production. The ubiquity of knowledge—Google in our pocket—raises the value of knowledge while at the same time lessening the distinctiveness of what occurs within what we once called the ivory tower. Thus Google today, to stay with this example, has approximately as many PhDs in its employ (~2000) as does Stanford. Now, universities remain conspicuous places for both the production (research) and consumption (education) of knowledge, and they may continue to be so in the future. But until very recently they were not merely conspicuous; they were singular, a role they have filled across various institutional permutations since the eleventh century. Students today have to be reminded that in the days before the Internet (1990!) one had to actually travel to a particular place (a library) to acquire what was then called "book learning." No longer: Knowledge production has gone rogue. Nor is the point limited to the ubiquity of the Internet: There is now more knowledge produced outside the academy than within it. In 2013 the top 10 companies in terms of research expenditures, from Volkswagen to Merck, spent more than 100 billion USD on research (Casey & Hackett 2014). By comparison, the budget of the US National Science Foundation in 2013 was $6.9 billion; the European Commission's Horizon 2020 averages around 11 billion euros a year from 2014 to 2020; and the 2014 budget of the Deutsche Forschungsgemeinschaft, the largest national research organization in Europe, was 2.8 billion euros.

These trends suggest that interdisciplinarity, as the totem of academic innovation, must embrace a different set of projects if it is to remain relevant across the next decades. The most pressing need is for an examination of the changing role of the university within society in an age of ubiquitous knowledge. Ironically, while interdisciplinarians criticize disciplinarity for a piecemeal approach to knowledge, they have not taken up the task of thinking through the function of the university as a whole. One way to frame this need is in terms of critical university studies (Williams 2016). For Williams, this implies an account of "the corporatization of American higher education over the past three decades." Fair enough: There are any number of indices, such as the rise of a contingent academic labor force (e.g., adjuncts) that support this point. But while neoliberalism represents a genuine challenge to academia—certainly among the distinctive aspects of the university are those elements that cannot be reduced to a paying basis—even more basic questions press themselves on us. What are the distinctive elements of the university that should remain viable in the future? What elements can be dispensed with, and which should be added? The STEM disciplines readily make arguments concerning their practical (that is, economic) efficacy, but the humanities have mostly failed in this regard. Can the humanities—especially at public universities—refashion themselves for an era focused on "impact?"

Ironically, given the wholesale attacks directed their way, the humanities may constitute the central feature of the twenty-first-century research university. Humanists are partially at fault here: They have been signal in their failure to provide an undated account of the impact of philosophy and of the humanities on society. The point should not be that difficult to make in an era when cultural products, creativity, style, and cultural imagination constitute so much of both the business and political worlds. But if an account of the impact of the humanities is needed, just as pressing is the need to develop a philosophy of impact. Questions of impact receive a great deal of attention within policy studies, but it is remarkable how little attention humanists, professors generally, and universities have given to the topic (Frodeman 2016).

Still the disciplinary division of labor remains paramount: Academic work remains piecemeal, even in those areas (i.e., the humanities) which used to claim with Hegel that "the truth is the whole." Thus a Google search for "institute/center for the future of the university" returns no hits; the same with attempts to locate academic programs devoted to the future of the university. Of course these are only indices; and as noted above, institutionalizing the nascent field of critical university studies presents its own problems in terms of disciplinary capture. There is still a crying need for a Manhattan Project–level effort to understand the place of the university within the ecology of twenty-first-century knowledge production and use.

What, then, is the problem that interdisciplinarity seeks to solve? I suggest it is one of politics, democracy, and technocracy. Interdisciplinarity is the bridge between academic sophists and the rest of society. "Sophist," of course, has come down to us as a term of disapprobation, but disciplinarians are by definition sophists, that is, people who are experts, who "know things." This is well and good, as long as we understand the limits (both political and epistemic) of expertise. But it does highlight the need for a class of thinkers who are adept at questioning rather than only providing answers, at opening up conversations, and at practicing the translational and transactional skills needed to connect the disciplinary sophistry to the community. To say it again, the point of interdisciplinarity is fundamentally rhetorical in nature: to figure out how to relate disciplinary expertise to the needs of the community while protecting the academic from undue harm.

By "undue harm" I mean the need to insulate academics from the negative consequences of speaking truth to power. Tenure has its problems, but its main one is that academics too rarely do anything that would demand its protections. On the other hand, the professorate should be justly held accountable when it does not recognize its dual loyalties—to the community that supports them (like Hegel, most of us are employed by the state) as well as to their disciplinary community. Academics, humanists included, are obliged to work on issues that connect up with the interests of the general public—though of course they do not owe that public the answers they desire.

As noted above, these questions were first identified by Plato. In the scholarly literature it has come down to us as "the relation of the philosopher to the *polis*." But put the point in contemporary terms: Society now demands greater accountability in return for its support of the academy. How are we to translate disciplinary knowledge into particular circumstances? What step-down functions do we have? Do we need disciplines to protect academics and/or to solve problems? And how do we at least partially sequester ourselves from simply becoming, or becoming seen as, one more political actor?

In sum, interdisciplinarity constitutes an implicit philosophy of knowledge—not simply an epistemology, but a general reflection on whether and to what degree knowledge can help us achieve the perennial goal of living the good life. It is a contemporary expression of a very old question.

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CHAPTER 2

KNOWLEDGE FORMATIONS

An Analytic Framework

STEPHEN TURNER

Knowledge is socially distributed, and the distribution of knowledge is socially structured, but the distribution and the structures within which knowledge is produced and reproduced—often two separate things—have varied enormously. Disciplines are one knowledge formation of special significance, for reasons that are explained in this chapter. They can be thought of as very old, or as a very recent phenomenon: In the very old sense, disciplines begin with the creation of rituals of certification and exclusion related to knowledge; in the more recent sense they are the product of university organization, and especially that part of university organization that joins research and teaching, knowledge production and reproduction, in the modern research university.

Interdisciplinarity, as an identifiable phenomenon with its own justification, begins as a response to disciplines in the modern sense of the term, and to the specific forms of the organization of disciplines in the modern research university as it emerged in the United States in the first two decades of the twentieth century (Graham & Diamond 1997). Interdisciplinary work has generated its own knowledge formations, which we consider at the end of the chapter. Yet interdisciplinarity, transdisciplinarity, and multidisciplinarity can also be thought of in terms of the older senses of "disciplines," and thus be given a long history.

In this chapter I give a general picture of the structural constraints on knowledge formations, introduce the idea of disciplines, and discuss the historical alternatives to disciplines and the motives for finding alternatives. I conclude with a discussion of the more recent history and some issues with current nondisciplinary forms. There is a literature on these issues, concerning such things as the internal organization of disciplines (Whitley [1984] 2000; Jacobs 2013; Collins 1998; Fuchs 1996). My approach is slightly different: to provide a general account of the preconditions and constraints under which knowledge formations that produce and reproduce knowledge operated, with a stress on the tensions between these constraints, and the various ways in which these tensions are managed.

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2.1 Some Basics of Knowledge Formation

To understand the range and differences between the various forms of the social organization of knowledge production and reproduction, it is useful to keep in mind some basic constraints that all of these forms operate under. These constraints can be handled or solved for in different ways, and it is the different combinations of solutions that produce the different forms. The issues of disciplinarity and those of forms of nondisciplinarity and interdisciplinarity make more sense in relation to these considerations, as do arguments for the reform of the current disciplinary order and its replacement. What follows is a list of what can be regarded as the basic elements of knowledge formations, of which disciplines are only one type.

2.1.1 Knowledge Sources

Knowledge has a history and source, and the sources constrain the way a knowledge formation is configured. There are multiple sources of "knowledge" but a basic set of distinctions might be borrowed from one of the most deeply rooted and historically important bodies of knowledge—law. A traditional distinction is made between (1) revelatory law, (2) rational law, and (3) customary law. A version of this might be adapted more generally: There is (1) knowledge that is eternal and unchanging and comes from a source appropriate to it; (2) empirical or factual knowledge, with a source in the changing world of empirical fact or socially constructed fact or even literary fashion; and (3) nonexplicit knowledge, involved in application, such as craft knowledge, or things learned as a tacit precondition to possessing the other kinds of knowledge. There is a difference between fields in which the participants generate the knowledge and those in which there are external sources, or supposed external sources, such as revelation, or the law as enacted by legislatures or passed down, that provide the core content of the subject matter. The type of knowledge involved is important as a determinant of the way in which it is taught, though arguably there are elements of each of these three sources in every knowledge formation.

Each of these, as a living body of knowledge that is transmitted and taught, involves a common language and a common understanding of that language, which is often specialized and distinct from ordinary language, as well as accepted forms of argument and reasoning, which are "shared" as a result of more or less standardized training or education of some kind that is a condition of communication rather than a form of communication. This tacit background may be highly specialized or relatively open and extensive, consisting of conversation and shared activity, or may be the product of quite rigid training hurdles, or a matter of overlapping areas of mutual intelligibility in which some of the common ground is very partial and unsystematic (see Galison 1997; Warwick 2003).

In the traditional disciplines central to the history of the European university there were dogmas—theological and legal—that students needed to master. Applying them was a different matter. Empirical knowledge and discovery played no role in these fields, but they did change through doctrinal refinement and gap filling. There were, moreover, tensions between these kinds of knowledge—between theory and practice, legal orthodoxy and application, and so forth—that generated new forms of knowledge production, including such things as casuistics and modes of empirical revision of principles and innovations in craft knowledge. The kinds of knowledge involved constrain the other parts of the knowledge formation.

2.1.1.1 *Resources*

Producing and reproducing knowledge requires people whose lives are to a significant extent dedicated to these tasks, and this means they must have sources of income that support the intellectual work that they do. The Romans sometimes had Greek slaves who advised and taught; tutors, secretaries, and librarians have often played this role, as have monks and priests. The arrangements vary widely, but both antedate and parallel the model of the university teacher.

2.1.1.2 *Means of Communication*

To the extent that new knowledge is generated or new interpretations are proposed, or even when the doctrine of the knowledge in question holds it to be complete or fixed but requires it to be taught and applied to new situations, some means of communicating this to others—"publication" in the literal sense of making known to some relevant persons—is essential.

2.1.1.3 *Norms of Conduct and Conventions of Discourse and Exchange*

Robert Merton wrote about the norms of science ([1942] 1973), describing a world that has largely vanished; Edward Shils did the same with the academic ethic (1984), and philosophers discuss the epistemic norms and values of science. Norms are part of the conditions for knowledge production and also of the reproduction of knowledge. These may vary significantly by field, and across time, but without them it is difficult for communication and exchange to result in something commonly recognized to be "knowledge." These norms, however, limit as well as facilitate communication, and because they vary from group to group and discipline to discipline, they are also the source of mutual incomprehension and disagreement.

2.1.2 Exclusion/Inclusion and Marks of Recognition

A pervasive feature of intellectual communities is the existence of marks of membership, explicit or implicit. Certification in the form of degrees, membership in societies or academies, peer review in a variety of contexts implying a definite notion of "peer," and the like are examples. Often there is a symbolic or ceremonial representation of membership, such as the granting of a degree, or some sort of physical evidence of having been trained.

2.1.2.1 *External Legitimacy*

Normally the community or group communicating knowledge has some sort of respect and recognition by nonmembers. This may be highly formal and come with a developed theory of the status of the particular kind of knowledge. The theory may be accepted by those who do not share the knowledge, or be part of the rationale for a particular institutional structure, such as an education system, bureaucratic order, or religious system. In the institutional history of the European university a particular hierarchy of faculties and their relations was important, had consequences for the development of knowledge, and was linked to the larger ecclesiastical order and its legitimacy. Schemes of public understanding of science and popular science as well as science education designed to instill respect for science are contemporary examples of proactive attempts to secure legitimacy, as is the use of press releases to announce research findings.

2.2 Solving for a Workable Structure: Why Disciplines Work

The conflict between teaching and research in the modern university is a familiar example of the tension between the constraints arising from the different problems of knowledge production and reproduction. The ideal of the scholar-teacher is a response to this tension, which solves the problem of resources by embedding the role within a university that supplies certification and generates income to support the scholar-teacher, and has acquired a generalized legitimacy on which the scholar-teacher can rely. This solution, in its usual forms, is associated with disciplinarization, because certification is done within the university mostly in terms of disciplines. Knowledge production is possible within this system because of the surplus extracted from the paying activity of reproduction or teaching, though this is increasingly supplemented and even replaced by the grant system, which diminishes, sometimes to nil, the role of reproduction. This provides one opening for going beyond disciplinarity, but nevertheless making such alternatives work requires that they provide a solution for the other constraints identified above.

One may think of the problem in this way: The constraints are a problem space in which there are many "solutions"—namely, knowledge formations, which need to achieve a certain stability over time, but which allow for a great deal of variation in the emphasis placed on each constraint and for a great deal of variation in the way each constraint is dealt with. The issue of legitimation is an example of the possible variations in solutions for a single constraint. Legitimation is for an audience. But audiences may vary, and may be satisfied in various ways. The model of "public understanding of science," to which we return later, is the product of a long history of thinking about the fundamental problem that results from the dependence of science on the public for support and the inability of the public to understand the content of science. A tradition that can be dated at least from Condorcet and expressed forcefully in the writings of Karl Pearson ([1892] 1911, 1919) argued that science education for the public was necessary, and that it should produce respect for scientists. Pearson went so far as to call for the public to regard scientists as priests (1888, p. 20). This idea was associated with a particular presentation of science through science education, directed especially at the working class, which taught elementary science with an eye to impressing students with the absoluteness of scientific truth and the power of science to manipulate the world.

An external presentation such as this does not determine an account of the nature of scientific knowledge internal to science itself, but it presents a problem of consistency: The practices of science and the practices and justifications internal to scientific practice cannot, unless there are barriers of secrecy, self-deception, and so forth, ignore the fact that what is taught externally takes a different form. The doctrine that there is a scientific method is a case in point. Long ridiculed by philosophers, and difficult to apply to much of what is normally recognized as science, the idea nevertheless persists as an external validator and means of policing the boundaries of science. The constraints involve both facing inward, to the community of knowers, and outward, to a public audience. Slogans like "the aim of science is to predict and control" serve similar purposes.

Disciplines solve the problem of resources by tying their internal processes—journal communication, associations, departments, degree programs, and so forth—to a hierarchical system that is both an internal and external market (Whitley [1984] 2000). The external market is the nonacademic market for graduates; the internal market is the exchange of graduates, both at the level of graduate students and PhDs and the movement of post-PhD scholars from position to position within the hierarchy. The strength of this system depends on its hierarchical character, for reasons that are explained shortly, and on its exclusive or monopolistic character. The issue of exclusive control is central: A discipline defines its domain, its objects of knowledge, and rejects the claims of others to intellectual authority over these objects. This does not mean that there is no contestation over topics and over who understands them best. But the tendency is for this contestation to be resolved by mutual respect for boundaries and the legitimacy claims that disciplines make externally and to other disciplines.

Disciplines prize their legitimacy and autonomy, and protect both in various ways: by standards, certification practices, licensing, and through the control of accepted means of communication. Typically disciplines have a professional association, a set of journals, meetings, and other structures. Facts like these go without saying: They are part of the everyday professional experience of contemporary academics. But these structures did not always exist, and the legitimacy of the disciplines themselves had to be established. The market character of the exchange of scholars—the fact that disciplinary departments are both buyers through hiring and sellers through producing—determines hierarchy, a hierarchy of market valuation of a degree from a certain department or graduate advisor, publication in a certain outlet or by a certain publisher, and so forth. The achievements of a scholar are implicitly valued and ranked. The value of an achievement is revealed by the importance that is placed on it in competitions for positions, grants, and so forth. Credibility, and the power to coerce other scholars to respond and take seriously particular work, is closely associated with these markers.

The phenomenon of intellectual "imperialism" is stigmatized precisely because it represents a disruption of these boundaries and a breakdown of the legitimacy claims on which they depend. Nevertheless, as Uskali Maki points out (2009, p. 353), expanding the explanatory domain of a theory is generally regarded as a good thing. It is evidence of the power of the theory and a source of new explanations for the target subject. So there is a tension between boundaries and monopolistic claims and quite ordinary processes of intellectual improvement. This conflict is at the heart of many of the criticisms of the system of disciplines (Jacobs 2013).

We can think of this conflict as arising from the way in which disciplines bind two things together: the production and reproduction of knowledge, teaching and research. There is nothing absolute about this binding: It is possible that, and indeed there are many cases in which, the production of knowledge is entirely divorced from any sort of training or instructional function. The story of how this happened can be briefly recapitulated. There were many knowledge formations that preceded the university, and existed—and to some extent still exist—parallel to and largely independent of universities. The university model is usually taken to have originated in the Islamic world, where there was a differentiation of faculties and a form of recognition of study, as well as funding by wealthy patrons, presumably with religious motivations, which also supported legal and clerical careers for the graduates.

In Europe, universities themselves initially followed one of two basic models. The universities of southern Europe were focused on law (especially canon law) and medicine, while those of northern Europe, principally Paris, but also later Oxford and Cambridge, focused on theology. In each of the latter cases they were essentially training schools for clerics. The colleges of the new world, such as Harvard and the Universidad Nacional Autnonoma de Mexico, founded in 1551 under the name Royal and Pontifical University of Mexico, were also oriented to this task. Harvard, until the twentieth century, was primarily a training school for Congregational ministers, and providing ministers was the motivation for founding many later American colleges.

The teaching of theology and law, as well as medicine, was not explicitly concerned with the *production* of knowledge: The sources of knowledge were given, external to the university, and took the form of dogma. "Discipline" meant the protection of the dogma. As late as the middle of the seventeenth century, "a Doctor of Medicine was compelled by the English College of Physicians to retest a proposition he had advanced in opposition to the authority of Aristotle under threat of imprisonment" (Rashdall [1895] 1936b, p. 453). Training was training in dogmas. There was a need to formulate these dogmas, and apply the dogmas in new circumstances, through legal and theological casuistry, and this led to a certain amount of innovation. But innovation was not prized.

These patterns were the distant source of a key element of the model of disciplines. It is worth recalling that much of what we take for granted today as a part of university education was inherited from the medieval university, which was oriented to the transmission of dogma alone. As the authors of the Cambridge historical survey of the medieval universities put it,

> It is not necessary that a definite line of study should be marked out by authority, that a definite period of years should be assigned to a student's course, or that at the end of that period he should be subjected to examination and receive, with more or less ceremony, a title of honour. All this we owe to the Middle Ages. (Rashdall [1895] 1936b, p. 459)

This was part of the inheritance of disciplinarization, but disciplines themselves, that is to say well-defined identities with markets of exchange of scholars and graduates, did not yet exist. Yet the rudiments of a market were there. The system, by licensing graduates of certain universities to teach anywhere, provided the means of mobility, and, through the system of disputations, scholars could distinguish themselves without doing anything to produce new knowledge.

Internal disciplinary hierarchies follow their own market logic: What is prized within the discipline is prized because it meets internal market needs. This is the basic fact of disciplinarity that runs through this chapter. The medieval universities had a form of this as well. The source of prestige in the market of the early university was the ability to attract students, especially students from afar. The thing that attracted them to the Italian universities was the systematic exposition of universal legal concepts in Roman and Canon law. In the case of law, adapting Roman law to local legal orders was an activity that was not general and not tied as closely to training in the system of Roman legal concepts. Hence it was not prized.

This, however, is a case of a fundamental conflict between activities in a predisciplinary setting. The great achievement of the legal scholars was the production of glosses on ancient texts. This is what they were there to lecture on and expound: legal dogma. The standardization of understandings of the law was essential to its value for students: Legal knowledge became transportable to other places, indeed "universal" at least to the universe of Europe. But this had a bad effect on scholarship. The original glossators were great scholars, and their influence was enormous. Their successors chose, or were condemned, to comment on them.

> The professors had come to busy themselves more with the gloss than with the text. Instead of trying really to develop the meaning of the text, they aimed at tediously exhaustive recapitulation and criticism of all the glosses and comments they could collect. In short, they lost sight of the aim of their work, which consequently became more and more stagnant and pedantic. (Rashdall [1895] 1936a, p. 257)

This was true, mutatis mutandis, of other domains of thought as well. In theology, "the 'Sentences' of Peter the Lombard" had "the same narrowing influence" (Rashdall [1895] 1936a, p. 256). The granting of advanced degrees reflected this emphasis on mastering a scheme of dogma or a system. Ironically, the key to the academic culture was disputations—over the received texts. Performance in these disputations was a mode of knowledge exhibition; but it was not oriented to sources of knowledge outside the canonical texts, either of theology or law. Philosophy was taught in the same way. Yet at the same time the teaching of dogmas was a solution to the problem of what it was that the scholars could sell. Students got what they wanted: They learned a common language that opened up to them the possibility of careers in state administration and the law, or in the Church.

One might wonder how the great philosophers of the period, such as Occam, Aquinas, and Duns Scotus, survived in this system. In fact they did not: Although they typically spent some time at the universities, for the most part they were part of the parallel educational system internal to the monastic orders. The monastic orders whose members contributed to intellectual life, such as the Dominicans and Franciscans, solved the problems of money and external legitimacy, in different ways. Both of these orders were mendicant, and in any case had their own hierarchies, which freed some of their members from other duties, and they had forms of collegial communication that extended across Europe, as well as means of publication through manuscripts and libraries maintained by the orders and Cathedrals—which themselves constituted an educational system.

2.3 The Scientific Revolution

The medieval university was a structure that lasted for centuries. It solved the problem of responding to the constraints listed above. It was, however, not good for the development of science. The scientific revolution happened for the most part outside the universities, and in different organizational forms, and with a different structure of patronage. The reformation and counter-reformation produced more changes, and the Protestant universities of the north, such as Leiden, freed from the limitations of clerical control, developed in new ways. These two stories, the development of nonuniversity knowledge formations and the development of the university into the modern disciplinary form, require some background.

The scientific revolution was carried out for the most part by nonacademics organized in groups and communicating with one another, as well as by some academics who were participants in learned circles outside the university and supported by patrons. They were either courtiers, such as Galileo (Biagioli 1993), often with positions such as court mathematician; or supported by their own wealth, such as Tycho, or by sinecures which allowed them to pursue their scientific work; or monks. A representative figure is Galileo's friend and supporter Federico Cesi (1585–1630), who founded the Accademia dei Lincei, a novel kind of institution whose "members lived communally and almost monastically in Cesi's house, where he provided them with books and laboratory equipment." The participants included Galileo, "the mathematician Francesco Stelluti, the physician Johannes Eck from the Low Countries, and the polymath Anastasio De Fillis" (Rice University http://galileo.rice.edu/gal/lincei.html). This list is a good indication of the range of participants in the scientific revolution. There was a moral content to their work as well: "not only to acquire knowledge of things and wisdom, and living together justly and piously, but also peacefully to display them to men, orally and in writing, without any harm," as a 1605 document of the academy put it (Rice University http://galileo.rice.edu/gal/lincei.html). This was an external face, but an internal code as well, and one at variance with that of the university, which prized its control of authority over knowledge.

The term "Renaissance man" is apposite: These people were not specialists in a discipline, but dabbled in various branches of knowledge, including theology and astrology. They benefited from personal contact with one another as well as from the circulation of books, a new technology of communication of the time, and the synergies provided by intellectual work in different domains and in contact with persons with different and varied interests. They also communicated with other circles, especially by letters but also by the new technology of printed books.

This process of creation of new communities combined with patronage continued in many more famous cases—the Royal Society, which began as meetings with no name at Gresham College—a nonuniversity non-degree-granting institution—before gaining Royal sponsorship in 1660. Paris followed in 1666, and other ambitious states and courts followed with their own versions. Leibniz convinced the elector of Brandenburg to establish what eventually was to be called the Prussian Academy of Science in 1710. It was funded, at the suggestion of Leibniz, by granting it a monopoly on the sale of calendars. One important innovation of these societies, a change both confirmed and advanced by the explicit rules generated by the British Royal Society, was in the rules of discourse (Lynch 2001). The practice of disputation, which had both defined and limited the medieval university, was replaced by the practice of experimental proof, and topics that were part of the tradition of disputation and not subject to experimental evidence were excluded. The academies were models of exclusion and inclusion that set the identity and hierarchy of scientists (Hahn 1971). Yet they were also schemes that solved problems of external legitimacy, especially by serving the state, and of course solved the problem of finance without depending on teaching.

The university system was not wholly resistant to the changes outside of it. Teaching, the primary activity, eventually morphed, in nonlegal and nontheological contexts, from teaching and disputing dogmatic systems into teaching one's own system. This was an evolution with peculiar intermediate points. As Constantine Fasolt points out, the expectation for a dissertation in the seventeenth century, and in many places long after, was that the student write up the professor's lectures. In many cases the professor wrote the dissertation himself (Fasolt 2004, pp. 96–97). The emphasis was on the defense, or *disputatio*, which proved the competence and in some sense the originality of the student performing the defense. There were many variations on this, but the idea that the student would reproduce and systematize the lectures of his teacher reflected the idea that one was transmitting a dogmatic system. But on becoming a professor, one presented lectures transmitting the system one propounded.

Freed of the control of the Church, the Protestant universities of northern Europe became hotbeds of this kind of teaching. This morphed again into a system in which a "Seminar" or protodepartment organized under a professor would teach the same doctrine, so that eventually there emerged multiple variant doctrines. Well into the last half of the twentieth century, indeed, this system prevailed at some universities, especially in Scandinavia. This was still not disciplinarization, however. That would require something more—an exchange of professors and students under a common label and a more or less common idea of the boundaries and exclusions implied by the label, and of the signs of membership. But the rise of Protestant universities, by freeing the market from the involvement of the church, allowed for a step in this direction.

The two major forms of knowledge organization, the Royal (and later national) Academies of science and the universities, together with various nonuniversity forms of public education and lecturing, developed in parallel over the last half-millennium, taking various forms, but sharing many features. Universities remained wedded to the practice of education as indoctrination into a dogma, proof of competence to some form of "defense" or disputation, and the building of intellectual systems by professors. The importance of each of these elements varied, but they were wedded to one another. Disciplinarization built on these practices, but transformed them in a different direction. Internal legitimation did not rest, as much on the power of individual professors to attract students or attract them to the system propounded by the professor, as on education in the discipline itself. Disciplines themselves sought and gained external legitimacy as disciplines, that is to say as the locus and guardian of specific competences and bodies of knowledge shared with others trained in the same discipline. And the definition of originality changed to reflect the practices of nonacademic circles, especially in science. Now something akin to discovery was a requirement for obtaining an advanced degree—though in reality discovery was rare, and the notion of originality extended to the most common kind of originality, the extension of established dogmas.

Between 1800 and 1910 the modern model of disciplinarization emerged and solidified. Along with it came discontents and anxieties about disciplinarization, involving the sense of a loss of the unity of knowledge (Weingart 2010). The process was led by the reformed universities of Germany, notably Halle and Göttingen (which demoted theology—a sign of the breakup of the old hierarchy of the university). Reform allowed new models of disciplinarization to develop. At Geissen, the chemist Wilhelm Liebig attracted and trained many foreign students, started a fertilizer and meat extract business, and became the model for modern science, combining research, teaching, and economic impact within the framework of a strong disciplinary structure. This model proved to be transportable: Its elements are found in the Land-grant universities of the United States in the last half of the nineteenth century, modified to become the ideal of teaching, research, and extension. In the late twentieth century this became the notion that a professor was to contribute to teaching, research, and service.

By the end of the nineteenth century a worldwide revolution in practice was beginning, with the idea of combining research and teaching at its core, and new hierarchies between universities developed, and new investment in universities, motivated by nationalism. The desire to emulate German universities led to the modern university in one country after another. Disciplines developed in association with licensing regulations or their de facto surrogates, and disciplinary organizations developed to define portions of academic turf. By 1910 the modern disciplines, and the modern research university, had been defined. The attempt to overcome disciplinary divisions followed in the twenties, under the influence of the Rockefeller philanthropies, and led in the 1950s to a movement for interdisciplinarity in teaching.

It goes without saying that much of the medieval regime of doctrinal reproduction persists in academic life, in part because of its preservation by the system of disciplinarization, which used its forms, especially the degree system. What separates researchers in different disciplines today is the way they are trained, and this includes "paradigms" and everything that is associated with them, as well as methods of argument, tacit understandings, instrumentation and the knowledge of how to use it, and so forth. However, perhaps the most important consequences of the system of disciplines for the intellectual substance of disciplines result from the hierarchies that develop through the market competition in the exchange of graduates and in the competition for research funds and other subsidies. The economist Milton Friedman, after retiring, while visiting a group of young economists, complained about the direction the discipline had taken, which he thought involved a substitution of mathematical prowess for intellectual substance. One of the younger economists responded by observing that this was what the market—by which he meant the internal market in economics as a discipline—demanded (cf. Frodeman, 2014). Because conformity is rewarded, the market produces a level of coercion that inculcates standards and attitudes that are very resistant to change.

2.4 The Interdisciplinary Alternative

This points to one of the three major strands of critiques of disciplinarity and to the various motivations for interdisciplinarity. The earliest critiques in the nineteenth century involved the ideal of the unity of knowledge, which disciplinarization threatened. Similar charges were made in the twentieth century about the threat to liberal education of a system which taught and rewarded disciplinary rather than educationally significant topics, or simply ignored topics that were not prestigious in the disciplines in which they would have been taught, such as film studies, a neglected child in both English departments and the Arts (Damrosch 1995, p. 61), but were nevertheless deserving of attention. Jerry Jacobs (2013) highlights several cases in which this kind of concern has led to interdisciplinary movements, but notes that they have tended to disciplinarize themselves. This should be no surprise: Teaching, or student demand for these areas, is the only available source of significant funding.

The important Rockefeller philanthropic response of the 1920s and 1930s concerned practical value: In the social sciences, for example, the Laura Spelman Rockefeller Foundation program supported the improvement of the social sciences in a "realistic" direction, with an aim of more or less rapidly producing useful knowledge. In the sciences, Rockefeller support was important to the phage group, a well-funded effort at integrating physics and biology that led to the molecular biology revolution: something that would not have occurred in the normal course of development within disciplinary zoology and botany departments. In the course of doing so they created new relationships through such institutions as Cold Spring Harbor. Philip Mirowski (2002) has pointed to the wartime RAND experience of many future economists with operations research and how its distinct cognitive value of minimalistic mathematical representation—in a nonacademic collective work setting—had major consequences for the development of postwar economics. The postwar bombing surveys, which brought together social scientists, psychologists, and psychiatrists, had formative effects on the postwar attempt to constitute these "behavioral sciences."

A significant part of these changes had to do with the creation of new, and for the most part temporary, social formations. But these needed to solve in some fashion the problems of coping with the constraints discussed earlier—particularly funding, external legitimacy, common norms and language, and so forth. Yet short-term structures like these can have long-term effects: The works of Aristotle were produced in an interesting collaborative "interdisciplinary" institution in one generation, but reproduced for two millennia.

Present discussions of changes in science and scholarship generally, notions of postacademic, postnormal, and Mode 2 science, have attempted to theorize these new forms of research, which are beyond the disciplinary. But they are faced with the same constraints; they simply deal with them in different ways. Each of the advantages of disciplinarity comes with limitations: the need to service students, the intellectual coercion that results from the disciplinary hierarchy that comes from the market exchange of students, the constraints on communication resulting from common training and norms, and the exclusions and limitations that go with them. Each limitation and exclusion produces an alternative unpopulated space, often involving practical problems, that "belong" to no discipline and cannot be easily addressed by any of them. The difficulties, however, are commensurate with the opportunities.

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CHAPTER 3

TYPOLOGIES OF INTERDISCIPLINARITY

The Boundary Work of Definition

JULIE THOMPSON KLEIN

Typologies classify phenomena based on similarities and differences, whether sorting artistic genres, medical symptoms, animal and plant species, or forms of knowledge. Over the course of the twentieth century, knowledge in the Western intellectual tradition was classified into specialized domains within a larger system of disciplinarity. In the latter half of the century, though, that system was supplemented and challenged by an increasing number of interdisciplinary activities. The most prominent way of organizing them has been to construct typologies that group related activities into categories labeled by technical terms.

The first major set of terminology appeared in 1970, created for an international conference co-sponsored by the Organization for Economic Cooperation and Development (OECD). It classified interactions of disciplines into categories of multi-, pluri-, inter-, and trans-discipinarity (Apostel 1972). Other labels soon followed, resulting in a profusion of jargon some have likened to a tower of Babel. Harvey Graff (2015), for one, faults the "name game" for generating more confusion than clarity, charging, "The endless typologies, classifications, and hierarchies of multi-, inter-, and transdisciplinarities are not helpful." Graff himself, though, adopts a hierarchical distinction between multi- and inter-disciplinarity throughout his comparative study of interdisciplines in order to reinforce integration as a primary criterion. More significant for this chapter, dismissing terminology fails to recognize its value for tracking definitions over time. Terms are sometimes used interchangeably, but patterns of consensus reveal continuities and discontinuities in theory and practice.

Typologies are neither neutral nor static. They reflect political choices of representation by virtue of what is included or excluded, which activities are grouped within a particular category, and how narrow or wide the field of vision is in a spectrum ranging from small academic projects to society at large. Taken together these choices constitute a form of boundary work in a semantic web that indexes differing purposes, contexts, degrees of integration and interaction, organizational structures, and epistemological frameworks. Thomas Gieryn (1983) coined the term "boundary work" in a study of demarcating science from non-science. He defined boundary work as an ideological style that constructs boundaries rhetorically in three major ways: expanding authority or expertise into other domains,

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monopolizing authority and resources, and protecting autonomy over professional activities. Interdisciplinary terminology performs all of these functions. It asserts alternative forms of research and education, often pegged against disciplinary specialization as the foundation of knowledge. It prioritizes some forms over others, in subcategories of interdisciplinarity and the heightened imperative of transdisciplinarity. And, networks and organizations use labels to stake claims for particular kinds of work. The three most widely used terms in the OECD typology constitute a core vocabulary amplified by technical distinctions for particular contexts.

The chapter distinguishes the first two generic terms—*multidisciplinarity* (MD) and *interdisciplinarity* (ID)—followed by major variants of methodological and theoretical ID, bridge building and restructuring, instrumental and critical ID. It then examines the current momentum for transdisciplinarity (TD) and closes by reflecting on implications of new typologies. Table 3.1 depicts key terms and their characteristics, degrees of integration, and contrasting types that appear throughout the chapter.

Table 3.1 Table of Definitions

Key Terms and Characteristics		
Multidisciplinarity	Interdisciplinarity	Transdisciplinarity
Juxtaposing Sequencing Coordinating	Interacting Integrating Focusing Blending Linking	Transcending Transgressing Transforming

Degrees of Interdisciplinary (ID) Integration	
Lack of Integration	Integration
Encyclopedic ID	Generalizing ID
Indiscriminate ID	Integrated ID
Pseudo ID	Conceptual ID
Contextualizing ID	Structural ID
Composite ID	Unifying ID

Contrasting Types	
Auxiliary Disciplinary Relations	Supplementary Disciplinary Relations
Bridge Building	Restructuring
Borrowing	Hybridization
Shared ID	Cooperative/Collaborative ID
Narrow ID	Broad or Wide ID
Methodological ID	Theoretical ID
Instrumental ID	Critical ID
Strategic or Opportunistic ID	
Endogenous ID	Exogenous ID
	Trans-sector Transdisciplinarity
	Coproduction of Knowledge

3.1 Multidisciplinary Juxtaposition and Alignment

Most definitions of ID, Lisa Lattuca found in a literature review, treat integration of disciplines as the "litmus test." In fields that prioritize critique of knowledge, this premise is disputed. Nevertheless, integration is the most common benchmark (2001, pp. 78, 109). The OECD typology classified MD as "[j]uxtaposition of various disciplines" (Apostel 1972, p. 25). Juxtaposition fosters wider scope of knowledge, information, and methods. Yet, disciplines remain separate, retain their original identity, and are not questioned. This tendency is widespread in conferences and publications that present serial views of a shared topic or problem. Likewise, many purportedly "interdisciplinary" curricula and research projects combine separate disciplinary approaches without proactively integrating them around a designed theme, question, or problem. The keywords in Rebecca Crawford Burns' typology of integrative education capture the limited relationship of disciplines and subjects. When placed in parallel order they are in a *sequencing* mode and when intentionally aligned a *coordinating* mode (1999, pp. 8–9). In both cases, however, integration is lacking.

3.1.1 Encyclopedic, Indiscriminate, and Pseudo Forms

This part of the spectrum of definition is often deemed superficial, reinforcing a boundary between MD and ID. As the keywords "sequencing" and "coordinating" suggest, MD is encyclopedic in nature. In a six-part typology, Margaret Boden deemed *encyclopedic ID* a "false" or "weak" form, citing loose communication in joint degrees and co-located information on the World Wide Web (1999, pp. 14–15). Similarly, Heinz Heckhausen categorized encyclopedic forms as *indiscriminate ID*, citing the *studium generale* of German education and exposure to multiple disciplines in professional education. Mindful of false claims, Heckhausen added the concept of *pseudo ID*, embodied in the proposition that sharing analytical tools such as mathematical models of computer simulation constitutes "intrinsic interdisciplinarity" (in Apostel 1972, pp. 87). Certain disciplines are also deemed "inherently interdisciplinary" because of their synoptic scope, including philosophy, literary studies, and religious studies as well as anthropology and geography. Synoptic identity signifies breadth more than integration of multiple parts. Despite falling short of ID, however, MD plays a valuable role in expanding the knowledge base for a given project or program and has even been deemed a characteristic of contemporary disciplines because of their plurality of practices.

3.1.2 Contextualizing, Informed, and Composite Relationships

The practice of applying knowledge from one discipline to contextualize another further illustrates the limits and value of MD. A philosopher might use history to inform readers about a particular movement in philosophy or, vice versa, use philosophy to provide epistemological context for a particular event. Boden's classification *contextualizing ID* is evident in another familiar practice, organizing discipline-based chapters serially in books on the same theme or topic. Proximity widens scope, but here too integration around shared themes or questions is lacking (Boden 1999, pp. 15–16). Heckhausen's term *composite ID* labels another familiar practice—applying complementary skills to address complex problems or to achieve a shared goal. He cited societal problems such as war, hunger, delinquency, and pollution, while calling peace research and city planning "interdisciplinarities in the making" because they simulate exploring interdependencies (in Apostel 1972, p. 88). Even with a common framework, though, knowledge production retains a strong disciplinary thrust. In biosciences, for example, technical knowledge from many fields and expensive instruments are often shared. Despite crossing boundaries, however, disciplinary relations do not necessarily change or individuals collaborate.

3.2 Interdisciplinary Integration and Collaboration

The OECD definition of ID was wide, encompassing any interaction ranging from "simple communication of ideas to the mutual integration of organizing *concepts, methodology, procedures, epistemology, terminology, data,* and organization of research and education" (in Apostel 1972, p. 25). Simple communication, though, does not entail key traits that Burns and Lattuca argue constitute ID. Integrated designs prioritize focusing, blending, and linking. In education for instance, courses achieve a more holistic understanding of a cross-cutting question or problem by combining historical and legal perspectives on public education or biological and psychological aspects of human communication (Burns 1999, pp. 11–12; Lattuca 2001, pp. 81–83). Scope varies though, ranging from narrow to wide or broad ID depending on the number of disciplines involved and the compatability of their epistemological paradigms and methodologies.

Many believe that ID is synonymous with collaboration. It is not. However, heightened interest in teamwork to solve complex intellectual and social problems has amplified the connection while fostering greater attention to the interaction of cognitive and social integration. Degrees of cooperation differ, though. In Boden's concept of *shared ID* groups tackle aspects of a complex problem. Yet, collaboration does not necessarily occur. In contrast, *cooperative ID* requires teamwork, exemplified by the collaboration of physicists, chemists, engineers, and mathematicians in the Manhattan Project to build an atomic bomb and in research on public policy challenges such as energy and law and order (1999, pp. 17–19). Differences are further evident in methodological versus theoretical ID.

3.2.1 Methodological Interdisciplinarity

The motivation in methodological ID is to improve the quality of results, typically by borrowing a method or concept from another discipline to test a hypothesis, to answer a research question, or to help develop a theory (Bruun et al. 2005, p. 84). Degrees of influence vary, though. If a borrowing does not result in a significant change in practice, Heckhausen explained, disciplines are in an *auxiliary* relationship. If it becomes more sophisticated and enduring dependence develops, the relationship is *supplementary*, exemplified by incorporation of psychological testing into pedagogy and neurophysiological measures in psychology (in Apostel 1972, pp. 87–89). In a six-part typology, Raymond Miller identified two forms of interdisciplinary work that are methodological in nature. The first, shared components, includes methods shared across disciplines, such as statistical inference. The second, cross-cutting organizing principles, are focal concepts or fundamental social processes used to organize ideas and findings across disciplines, such as "role" and "exchange" (1982, pp. 15–19). New engineering and technological methods were also developed during World War II, stimulating postwar borrowings of cybernetics, systems theory, information theory, game theory, and new conceptual tools of communication and decision theories. And, the roster of shared methods includes techniques such as surveying, interviewing, sampling, polling, case studies, cross-cultural analysis, and ethnography.

Borrowing across social sciences and humanities also illustrates methodological ID. In 1980, Clifford Geertz identified a broad shift within intellectual life in general and social sciences in particular. The model of physical sciences and a laws-and-instances explanation was being supplanted by a case-and-interpretation model and symbolic form analogies borrowed from humanities (see Krohn, this volume). Social scientists were increasingly representing society as a game, a drama, a text, or a performance, rather than a machine or a quasi-organism. They were borrowing methods of speech-act analysis, discourse models, and cognitive aesthetics, crossing the traditional division of explanation and interpretation. And, social sciences were not immune from the influences of existentialism and phenomenology, structuralism, deconstruction, poststructuralism, neo-Marxism, and comparative cultural studies. On the other side of the disciplinary fence, humanists were taking anthropological, sociological, political, and historical turns in scholarship while borrowing concepts of "motives," "authority," "persuasion," "exchange," and "hierarchy." Conventional rubrics remain, Geertz concluded, but they are often jerry-built to accommodate a situation that is "fluid, plural, uncentered, and ineradicably untidy."

3.2.2 Theoretical Interdisciplinarity

Theoretical ID connotes a more comprehensive general view and epistemological form embodied in creating conceptual frameworks for analyzing particular problems, integrating propositions across disciplines, and synthesizing continuities between models and analogies. The Academy of Finland Interdisciplinary Research (AFIR) team cited a project to develop a model of mechanisms that mediate mental stress experiences into physiological reactions and eventually coronary heart disease. Previous studies emphasized correlation of single stress factors or separate personal traits associated with the disease. In contrast, the project aimed to develop an interdisciplinary theory based on integration of psychological and medical elements and testing the conceptual tool of inherited "temperament" (Bruun et al. 2005, p. 86).

Theoretical forms of ID are often ranked as more "genuine" than methodological forms. For Boden, the highest levels are *generalising ID* and *integrated ID*. In generalizing ID, a single theoretical perspective applies to a wide range of disciplines, such as cybernetics or complexity theory. In integrated ID, which Boden deems "the only true interdisciplinarity," concepts and insights of one discipline contribute to problems and theories of another, a process evident in computational neuroscience and the philosophy of cognitive science. Individuals may also find their disciplinary methods and theoretical concepts modified as a result of cooperation, fostering new conceptual categories and methodological unification (1999, pp. 19–22). Comparably, Lattuca considers *conceptual ID* the "[t]rue or full" form of ID. Core issues and questions lack a compelling disciplinary basis, and critique of disciplinary understanding is often implied (2001, p. 117). Parallels also arise in the difference between bridge building and restructuring.

3.3 Bridge Building versus Restructuring

In 1975 the London-based Nuffield Foundation's Group for Research and Innovation identified two basic metaphors of ID—bridge building and restructuring. Bridge building occurs between complete and firm disciplines, while restructuring detaches parts of several disciplines to form a new coherent whole. A third possibility occurs when a new overarching concept or theory subsumes theories and concepts of several disciplines, akin to the notion of TD (Group for Research and Innovation, 1975, pp. 42–45). Landau, Proshansky, and Ittelson's typology of two phases in the history of interdisciplinary approaches in social sciences illustrates the difference between bridge building and restructuring. The first phase, dating from the close of World War I to 1930s, was embodied in the Social Science Research Council and University of Chicago school of social science. The interactionist framework at Chicago fostered integration, and members of the Chicago school were active in efforts to construct a unified philosophy of natural and social sciences. The impacts were widely felt, and occasionally disciplinary "spillage" led to formation of hybrid disciplines, such as social psychology and political sociology. However, traditional categories of knowledge and academic structures remained intact.

The second phase, dating from the close of World War II, was embodied in "integrated" social science courses, a growing tendency for interdisciplinary programs to become "integrated" departments, and the concept of behavioral science. Traditional categories anchoring disciplines were questioned and boundaries blurred, paving the way toward a new theoretical coherence and alternative divisions of labor. The behavioral science movement, in particular, sought an alternative method of organizing social inquiry rather than tacking imported methods and concepts onto traditional categories. In addition, the concept of "area" posited greater analytical power while stimulating a degree of theoretical convergence also potential in the concepts of role, status, exchange, information, communication, and decision-making (Landau et al. 1962, pp. 8, 12–17).

3.3.1 Interdisciplinary Fields, Interdisciplines, and Hybrid Specializations

The formation of new interdisciplinary fields is a major case of restructuring. Miller identified four categories in a typology of interdisciplinary approaches. *Topics* are associated with problem areas. "Crime," for instance, is a social concern appearing in multiple social science disciplines as well as criminal justice and criminology. "Area," "labor," "urban," "environment," and "the aged" also led to new academic fields. *Life experience* became prominent in the late 1960s and 1970s with the emergence of ethnic studies and women's studies. *Hybrids* are "interstitial cross-disciplines" such as social psychology, economic anthropology, political sociology, biogeography, culture and personality, and economic history. And, *professional preparation* led to new fields with a vocational focus, such as social work and nursing.

Some new fields are considered a hybrid type of ID. When new laws become the basis for an original discipline, Marcel Boisot contended, a more formal *structural* relationship emerges, such as electromagnetics and cybernetics (in Apostel 1972, pp. 94–95). Heckhausen also deemed the point at which biology reached the subject matter level of physics and biophysics an example of *unifying ID* (in Apostel 1972, pp. 88–89). Proposing hybridization as a general process of development, based on studies of innovation in social sciences, Dogan and Pahre identified two stages. The first is specialization, and the second continuous reintegration of fragments of specialties. They also identified two types of hybrids. The first type becomes institutionalized as a subfield of a discipline or a permanent cross-disciplinary program. The second type, exemplified by the topic of "development," remains informal. Hybrids, moreover, beget other hybrids, especially in natural sciences where higher degrees of fragmentation and hybridization are present (1990, pp. 63, 66, 72).

The emergence of new communities of practice and networks often leads to proclamations of a new discipline, perpetuating an oversimplified belief that the interdiscipline of today is the discipline of tomorrow. This generalization, however, ignores wide variances in both interdisciplines and disciplines (Graff 2015). Some areas, such as systems science, have gained disciplinary status, anchored by shared principles, unifying core concepts, and a new community of knowers with a common interlanguage. Others though, such as nanoscale research, are widely dispersed and bounded within individual domains. Economic and social capital are also powerful determinants in the political economy of ID. The growth of area studies, for instance, was facilitated by significant amounts of funding from the Ford Foundation. Molecular biology also enjoyed a level of support lacking in social psychology, and the same discrepancy appears today in the differing status of biomedicine and digital humanities.

More than one label might apply in the same field as well, depending on which points of interaction and degrees of integration are being described. Richard Lambert (1991) called the field of area studies, for example, a "highly variegated, fragmented phenomenon, not a relatively homogeneous intellectual tradition." Much of what could be called "genuinely interdisciplinary" work, he judged, occurred at the juncture of four disciplines providing the initial bulk of area specialists: history, literature and language, anthropology, and political science. At that hybrid space, a historically informed political anthropology developed using material in local languages. Blending of disciplinary perspectives occurred most often at professional meetings and in research by individual specialists. In scholarly papers the dominant pattern was broadly defined themes, creating a collective "multidisciplinary" perspective with the topic of any one event driving the disciplinary mix. At the same time, area studies research is "subdisciplinary" when concentrated in particular subdomains, even as the field at large is deemed "transdisciplinary" in scope.

3.4 Instrumental versus Critical Interdisciplinarity

The difference between instrumental and critical ID is another fault line in the discourse of ID. In an analysis of forms of interdisciplinary explanation, Mark Kann identified three political positions. Conservative elites want to solve social and economic problems, without concern for epistemological questions. Liberal academics demand accommodation but maintain a base in the existing structure. And, radical dissidents challenge the existing structure of knowledge, demanding ID respond to the needs of oppressed and marginalized groups (1979, pp. 187–188). Methodological ID is "instrumental" in serving the needs of a discipline or field. During the 1980s, however, another kind of instrumental ID akin to Kann's first political position gained priority in science-based areas of economic competition such as computers, biotechnology and biomedicine, manufacturing, and high-technology industries. Peter Weingart labeled related activities *strategic* or *opportunistic ID* that serves the needs of the marketplace and the nation (2000, p. 39).

In contrast, critical ID interrogates the dominant structure of knowledge and education with the aim of transforming it, raising questions of value and purpose silent in instrumental ID. New fields in Miller's "life experience" category were often imbued with a critical imperative, older fields such as American studies took a "critical turn" in the 1960s and 1970s, and a "new interdisciplinarity" emerged in humanities and cultural studies signified by "anti," "post," "non," and "de-disciplinary" labels. Indicative of this trend, Lattuca found an increasing number of faculty in humanities and social sciences do interdisciplinary work with the explicit intent of deconstructing disciplinary knowledge and boundaries, blurring boundaries of the epistemological and the political (2001, pp. 15–16, 100).

Critical ID also refigures the relationship of disciplinarity and ID. Giles Gunn (1992) depicted differing constructions of the relationship in a typology of interdisciplinary approaches in literary studies. The simplest approach to mapping is tracking relations with other disciplines, for instance literature *and* philosophy or anthropology. Each coupling exposes cross-secting influences, such as hermeneutics in the relationship with philosophy or ethnography with anthropology. The conjunctive strategy, though, remains on disciplinary ground. The map changes if asking a different question. What new subjects and topics have emerged? Other examples appear, such as history of the book, psychoanalysis of the reader, the sociology of conventions, and ideologies of gender, race, and class. Studies of textuality also evolved into studies of representation. "The threading of disciplinary principles and procedures," Gunn found, "is frequently doubled, tripled, and quadrupled in ways that are not only mixed but, from a conventional disciplinary perspective, somewhat off center." They are characterized by overlapping, underlayered, interlaced, crosshatched affiliations, collations, and alliances that have ill-understood and unpredictable feedbacks. The final development is the most difficult to map. Correlate fields such as philosophy and anthropology have themselves changed, challenging assumptions about the strength of boundaries while working to erode them. Gunn concluded, "The inevitable result of much interdisciplinary study, if not its ostensible purpose is to dispute and disorder conventional understandings of relations between such things as origin and terminus, center and periphery, focus and margin, inside and outside."

The distinction between instrumental and critical forms, it should be said, is not absolute. Research on problems of the environment and health often combine critique and problem solving. Nonetheless, a clear division appears in typologies. Observing trends in the medical curriculum, Bryan Turner (1990) argued that pragmatic questions of reliability, efficiency, and commercialism take center stage when ID is conceived as a short-term solution to economic and technological problems. In contrast, in social medicine and sociology of health ID emerged as an epistemological goal focused on the complex causality of illness and disease. Researchers focused on psychological, social, and ethical factors in an alternative holistic biosocial or biopsychosocial model that is critical of the limits of the traditional hierarchical biomedical model.

(See Frodeman [2013] and Jacobs [this volume] for two contrasting views of the relationship of disciplines and ID, the first asserting dissolution of disciplines while prioritizing problem-focused TD and the second reasserting the primacy of disciplines.)

3.5 Transdisciplinarity

The recent ascendancy of TD is a prominent development in the history of ID. In the OECD typology, TD was defined as a common system of axioms that transcends the scope of disciplinary worldviews through an overarching synthesis, such as anthropology conceived as the science of humans. Three participants in the OECD seminar differed, though, in elaborating the concept. Jean Piaget treated TD as a higher stage in the epistemology of interdisciplinary relationships based on reciprocal assimilations. Andre Lichnerowicz promoted "the mathematic" as a universal interlanguage, and Erich Jantsch embued TD with social purpose in a hierarchical model of the system of science, education, and innovation (in Apostel 1972). Since then, the term has proliferated. Four major trendlines appear at present.

The first trendline is a contemporary version of the epistemological quest for systematic integration of knowledge. The quest for unity spans ancient Greek philosophy, the medieval Christian *summa*, the Enlightenment principle of universal reason, Hegelian philosophy, Transcendentalism, the search for unification theories in physics, and E. O. Wilson's theory of consilience. Reviewing the history of TD, Joseph Kockelmans (1979) found it has tended to center on educational and philosophical dimensions of sciences. The search for unity today, though, does not follow from a pregiven order. It must be continually "brought about," Kockelmans emphasized, through critical, philosophical, and supra-scientific reflection. It also accepts plurality and diversity, an underlying value of the Centre International de Recherches et Études Transdisciplinaire (CIRET). The center is a virtual meeting space for a new universality of thought and type of education informed by the worldview of complexity in science.

The second trendline is an extension of the OECD definition of synthetic paradigms. Miller defined TD as "articulated conceptual frameworks" that transcend the narrow scope of disciplinary worldviews. Leading examples include general systems, structuralism, post-structuralism, Marxism, phenomenology, feminist theory, and sustainability. Holistic in intent, these frameworks propose to reorganize the structure of knowledge by metaphorically encompassing parts of material fields that disciplines handle separately (1982, 21; see also Stribos, this volume). In the early twenty-first century a variant of this trendline emerged in North America in the concept of "transdisciplinary science" in broad areas such as cancer research. It is a collaborative form of "transcendent interdisciplinary research" that creates new methodological and theoretical frameworks for analyzing social, economic, political, environmental, and institutional factors in health and wellness (see Hall et al., this volume).

The third trendline is akin to critical ID. Transdisciplinarity is not just "transcendent" but also "transgressive." In the 1990s, TD began appearing more frequently as a label for knowledge formations shaped by critical imperatives in humanities, critiques of disciplinarity, and societal movements for change. Tracking the history of ID in Canadian Studies, Jill Vickers (1997) linked TD and "antidisciplinarity" with movements that reject disciplinarity in whole or in part, while raising questions of sociopolitical justice. Examples include women's, native/aboriginal, cultural communications, regional, northern, urban, and environmental studies. Antidisciplinary positions have also moved beyond the academic sphere, favoring materials in ways dictated by students' own transdisciplinary theories, cultural traditions, lived experience, and connotations of "knowledge" and "evidence."

The fourth trendline prioritizes problem solving. It was evident in the late 1980s and early 1990s in Swiss and German contexts of environmental research. By the turn of the century case studies were reported on an international scale and in all fields of human interaction with natural systems and technical innovations as well as the development context. The core premise is that problems in the *Lebenswelt*—the lifeworld—need to frame research questions and practices, not disciplines. This connotation is strong in projects, such as Global TraPs (Global Transdisciplinary Processes on Sustainable Phosphorus Management), and in groups such as td-net (Network for Transdisciplinary Research). Co-production of knowledge with stakeholders in society is a cornerstone of this trendline, realized through mutual learning and a recursive approach to integration (see also Pohl et al., this volume).

The fourth trendline also intersects with two prominent concepts in the discourse of TD—"postnormal science" and "Mode 2 knowledge production." They stand in striking contrast to the intellectual climate of the 1970 OECD seminar, shaped by the organizing languages of logic, cybernetics, general systems theory, structuralism, and organization theory. Postnormal science is associated with TD because it breaks free of reductionist and mechanistic assumptions about how things are related and systems operate. "Unstructured" problems are driven by complex cause–effect relationships, and they exhibit a high divergence of values and factual knowledge. Hence, they are associated with the concept of "wicked problems" (see Bammer, this volume.)

Gibbons et al. (1994) also proposed that a new mode of knowledge production has emerged. Mode 1 is characterized by hierarchical, homogeneous, and discipline-based work; Mode 2 by complexity, nonlinearity, heterogeneity, and TD. New configurations of research are being generated continuously, and a new social distribution of knowledge is occurring as a wider range of organizations and stakeholders contribute skills and expertise to problem solving. Gibbons et al. initially highlighted instrumental contexts of application, such as aircraft design, pharmaceutics, and electronics. Subsequently, though, Nowotny et al. (2001) extended Mode 2 theory to argue that contextualization of problems requires participation in the *agora* of public debate, incorporating the discourse of democracy. When lay perspective and alternative knowledges are recognized, a shift occurs from solely "reliable scientific knowledge" to inclusion of "socially robust knowledge."

3.6 The Reportage of Change

National reports are important barometers of change. The 2005 *Facilitating Interdisciplinary Research*, published by the National Research Council (NRC) in the United States, identified four drivers of interdisciplinarity today:

(1) the inherent complexity of nature and society
(2) the desire to explore problems and questions that are not confined to a single discipline
(3) the need to solve societal problems
(4) the power of new technologies
(Committee on Facilitating Interdisciplinary Research, 2005, pp. 2, 40).

Drivers (1), (2), and (3) are not new. They have intensified, however, in recent decades. Driver (3) escalated with mounting pressure on universities to solve "real-world" problems, and driver (4) is propelled by the expanding power of generative technologies such as magnetic resonance imaging and advanced computing power for sharing large quantities of data.

The growth of interdisciplinary fields also has implications for typology. After evaluating the methodology of classifying research-doctorate programs, members of a 2003 NRC study recommended increasing the number of recognized fields from 41 to 57, renaming biology "life sciences" while including agricultural sciences, and listing subfields to acknowledge their expansion. Mathematics and physical sciences, the authors added, should be merged into a single major group with engineering. Their final 2009 report highlighted life sciences while adding a field of "biology/integrated biomedical sciences" and noting the expanding fields of public health, nursing, public administration, and communication. In addition, Appendix C called attention to emerging fields of bioinformatics; biotechnology; computational engineering; criminology and criminal justice; feminist, gender, and sexuality studies; film studies; information science; nanoscience and nanotechnology; nuclear engineering; race, ethnicity, and postcolonial studies; rhetoric and composition; science and technology studies; systems biology; urban studies and planning (Ostriker & Kuh 2003; Ostriker et al. 2009).

In 2010 a Panel on Modernizing the Infrastructure of the National Science Foundation's Federal Funds for R&D Survey called further attention to the problem of outdated classifications. The R&D Survey provides data on spending and policy in the United States. However, the taxonomy for fields of science and engineering had not been updated since 1978. The terms "typology" and "taxonomy" are often used interchangeably, but typology is technically conceptual in nature and "taxonomy" is an empirical ordering based on measurable characteristics. The methodology of measurement in the R&D survey was outdated, failing to capture increases in the multi- and interdisciplinary character of science. Also, activities were lumped into a large category of "not elsewhere classified" that includes new subfields, emergent fields, established interdisciplinary fields, cross-cutting initiatives, problem-focus areas, and the amorphous designation "other." In their final report, the Panel recommended capitalizing on new technologies to federate, navigate, and manage data while citing the

National Institutes of Health Research Condition and Disease Classification (RCDC) database as a model of a bottom-up approach to taxonomy and permitting users to construct crosswalks among categories.

A final report accounts for new horizons of research and the growing momentum for TD. The 2014 NRC volume *Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond* defined convergence as an "expanded form of interdisciplinarity" that fosters a higher level of synthesis connoted by TD (Committee on Key Challenge Areas for Convergence and Health 2014). The report positioned convergence historically as a stage beyond two earlier "interdisciplinary" revolutions of molecular and cellular biology and of genomics. Convergence represents a new stage in bringing together bodies of specialized knowledge to constitute "macro" domains of research activity that generate ideas, discoveries, tools, and methodological and conceptual approaches. Tangible outcomes include tissue engineering, advances in cognitive neuroscience, and improved energy storage for securing food supplies in a changing climate. Convergence advances basic research but it also leads to new inventions, treatment protocols, and forms of education and training while fostering partnerships among academic researchers and stakeholders in private and public sectors. In prioritizing product development and speeding up translation of findings from the scientific bench to bedside, convergence does not just blur the boundaries of the academy, industry, and government. It erases them, while aligning ID and TD with academic capitalism.

Reflecting on the current discourse of ID and TD, Weingart identified a common topos among claims for new modes of knowledge production, postnormal and postmodern science, and newer forms of inter- or transdisciplinary research. They are all oscillating between empirical and normative statements, reinforcing democratic and participatory modes while resounding the theme that triggered escalation of ID in higher education reform during the 1960s. Now, however, claims are situated in the context of application and involvement of stakeholders in systems that are too complex for limited disciplinary modes portrayed as too linear and narrow for "real-world" problem solving. New TD and counterpart ID forms, though, are not without their own "blind spots," including failing to recognize opportunistic dimensions of both presumably "internal" academic science and strategic research for nonscientific goals. Moreover, theoretical claims are frequently overstated. Mode 2, postnormal science, and other schemes, Weingart contended, look at phenomena only on the surface, describing institutional changes rather than a new epistemology (2000, pp. 36, 38).

Ultimately, the question of knowledge cannot be separated from how we talk about it. Terminology is not simply a reflection of reality. It is a form of boundary work that filters and directs attention. Proclaiming that ID or TD has only one purpose—be it holism or problem solving—ignores the fact that ID is a contested discourse. One strand of problem solving, for instance, centers on collaborations between academic researchers and industrial/private sectors for innovations in product development. A different type occurs when academic experts and actors in society coproduce knowledge in the name of democratic solutions to the challenges of sustainability. Plurality does not spell cacophony, however. Terms are rhetorical signposts of continuity and change, tradition and innovation. They reassert, extend, interrogate, and reformulate existing classifications to address both ongoing and unmet needs.

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The Need for Disciplines in the Modern Research University

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In this century, the adjective "interdisciplinary" has come to have a generally positive valence, as it is used as a synonym for concepts such as "innovative research" and "integrated solutions" (Frodeman et al. 2010). Whatever value cross-field connections might have, it does not necessarily follow that disciplines represent a negative aspect of university life. This sidebar presents key points from my book *In Defense of Disciplines*.

Let us start at the beginning: What are disciplines, and why do they exist? As I am using the term, a discipline is a self-regulating body of researchers and scholars based in a university. In the liberal-arts context, a discipline refers to fields in which there is a department, a major, and a doctoral degree. A field may be regarded as a discipline when professors with specified credentials are typically hired to conduct research and teach students in a particular domain. This definition focuses on the social organization of a field and makes no direct claims about its internal coherence or boundaries, although some degree of intellectual integration is needed before a field can become institutionalized.

The most successful disciplines, such as psychology, history, and economics, are established at the great majority of research universities and teaching colleges in the United States. To accomplish this degree of acceptance requires a substantial degree of support, from colleagues in other fields, deans, funding agencies, prospective students, and potential employers. A successful discipline will thus have considerable cultural authority and legitimacy.

The ubiquitous disciplines are also typically broad enough in scope to convince even small institutions to include the field in their portfolios. Biology and sociology are well-established fields in most institutions, while narrower fields of inquiry such as archeology, criminology, demography, and linguistics usually do not have their own departments, majors, or degrees. The former are well-established liberal arts disciplines, while the latter are important academic specialties that are less well established.

The breadth of disciplines is accompanied by substantial internal differentiation. Specialties abound, creating lively (and sometimes unpleasant) internal politics.

In economics, for example, the *Journal of Economic Literature* classification system divides economics into 20 general categories, which in turn contain over 134 divisions and 811 areas of specialization (American Economic Association 2015). Rivalries between specialties can also generate fruitful competition. Sparks generated by intellectual conflict yield lively battles but generally propel scholarship forward. Moreover, intellectual brokers can cross-fertilize specialties within disciplines just as they do between fields.

Another question arises: Why do disciplines exist? Disciplines are an organizational manifestation of the need for an academic division of labor. The extent of contemporary scholarship is so vast that no single person could master all of it. There are currently over 30,000 academic journals that employ peer review, and this total is growing by about 3% per year due to the creation of online journals and publications based in countries striving to join the international research community (author's analysis of Ulrich Periodical data). There is thus a need to divide the intellectual terrain into fields of inquiry, even while practitioners know full well that extant dividing lines are fuzzy and sometimes arbitrary.

In addition, disciplines exist because research and scholarship have an important social dimension. It is not enough for a lone scholar to come up with brilliant insights on her own. These insights need to be recognized, organized with other relevant theories and findings, and taught to the next

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generation. Disciplines are designed with these tasks in mind. They are forms of social organization that evaluate, organize, and disseminate research and scholarship. Moreover, insights are typically refined and extended over time, tasks that occupy the lion's share of research work.

The definition presented here belies some of the principal critiques that have been leveled against disciplines (e.g., Pearson 2015). Disciplines are not static but are dynamic. In addition to competition between individuals seeking academic stardom, internal competition between subfields and competition between departments over students, resources, faculty lines, research funding programs, and space on campus generates pressure to innovate.

Nor are disciplines isolated silos. All fields are intellectual amalgams with ideas, metaphors, and methods borrowed from other domains. As Graff (2015) has shown, the interdisciplinary roots of disciplines are evident in the formation of fields spanning the natural sciences, social sciences, and humanities.

Individual researchers can sometimes feel like they are in a silo because it is difficult if not impossible to keep up with the abundance of new research. Yet ideas and techniques from diverse sources are embraced, and often quickly. In other words, while it is difficult if not impossible for any given individual to keep up with the latest development in neighboring fields, it is also difficult if not impossible to keep new ideas out. Disciplines are porous, and active researchers find that they must keep up.

In my book, I present several distinct types of evidence to document the fact that disciplines are open to ideas from diverse fields. For one, academic research frequently draws on information from a range of sources that traverse academic boundaries. Methods such as statistics, for example, are quickly assimilated irrespective of the discipline in which they originated. For example, Cox regression and related statistics were adopted rapidly in many fields, whether they are referred to as "event history models" in sociology or measures of "survival" rates in oncology research and "failure rates" in engineering studies.

Finally, disciplines are porous not only because of their physical proximity on campus but also because of the ubiquity of research centers. Each of the top 25 research universities on average has more than 100 research centers, most of which claim to be interdisciplinary in scope (author's analysis of institutional data from Gale Ready Reference Shelf). American universities are thus hybrids—discipline-based departments coexist with interdisciplinary research centers.

This characteristic of research universities does not mean that neighboring fields accept or assimilate all of the knowledge of other fields. But those who emphasize the difficulty that scholars have in communicating across fields sometimes exaggerate. Even the anthropological study of academic "tribes," emphasizes the blurred boundaries and ease of communication between fields, especially since the 1990s (Becher & Trowler 2001).

While critics of disciplines maintain that they are narrow-minded coteries compared with broadly integrative interdisciplinary programs, evidence from the institutionalization of fields supports the opposite conclusion. Disciplines, as we have seen, are typically quite broad in scope, while many interdisciplinary topics are quite narrow in focus. An interdisciplinary area may well resemble a scholarly niche rather than broad bridge between diverse intellectual terrains.

1 Disciplines and Real-World Problems

The case is sometimes made that the world's problems are too big to be addressed by any one discipline, and that interdisciplinary teams and programs are needed to tackle the challenges posed by climate change, pandemics, global inequality, and other daunting issues (Bhaskar et al. 2010). While it is often the case that solutions require coordinated efforts, it is another matter entirely to suggest that integrated research teams are needed to provide the knowledge base on which these strategies are based. In other words, the conclusion that we need "integrated research" does not follow from the fact that we need "integrated programmatic strategies." The philosopher Gilbert Ryle (1949) would likely have called this a "category mistake."

Take the case of the outbreak of Ebola in western Africa. An international epidemic of this scale and lethality required a coordinated response from public health officials, government agencies, and volunteer groups operating at the national and international level. Yet the outbreak of Ebola also generated a tremendous amount of new discipline-based research classified under the headings of diagnostics, therapeutics, vaccines, and basic research by the National Institutes of Health (2015), which is the source of much of the funding in this area. Biomedical scientists rushed to develop new vaccines and new treatments as well as quick and inexpensive tests for the presence of Ebola. At the same time, public health workers coordinated data from outbreaks in order to more effectively target resources, epidemiologists tracked survival rates, others designed new Ebola protective gear to reduce the risk to healthcare workers, and cultural anthropologists worked to understand local customs and beliefs that might spread the disease and impede treatment. While it is certainly important that all involved are aware of the latest news and developments, those developing vaccines do not need to help build new protective suits. Similarly, anthropologists need to understand mechanisms of diffusion but not necessarily to participate in basic research on the genetic structure of the virus. It is best to view the response to Ebola as a multifaceted challenge that requires the insights of a wide range of specialized researchers. The same holds true for other complex social issues such as climate change.

Disciplines, however messy and diverse, are essential organizational units of modern universities. They are part of a hybrid system that combines discipline-based departments and interdisciplinary research centers, blends research and teaching, is somewhat insulated from everyday demands, yet ultimately depends on legitimacy and support from multiple publics. In short, disciplines are dynamic because of internal and external competition, and also because they constitute a social structure that channels this dynamism.

Discipline-based scholars are by no means flawless. They can pursue blind alleys, ignore if not stifle the next great idea, and occupy too much of their time with unproductive infighting. Disciplinary leadership is also confronted from time to time by intellectual movements that challenge prevailing ideas (Frickel & Gross 2005). But it is one thing to try to overthrow a particular set of discipline-based heuristics and another entirely to say that we should dispense with heuristics altogether (Liu 2008). Without a self-regulating system of scholarly appraisal, it is hard to imagine how scientific and scholarly advances could be developed, appraised, refined, and taught. Academic systems can sometimes be too structured, too constraining. However, the solution is the development of alternative frameworks that are broader and more encompassing, not rejection of frameworks themselves.

2 Interdisciplinarity, Balkanization, and the Concentration of Academic Power

Interdisciplinarity can shift power from researchers and departments to deans and presidents, as critics of the interdisciplinary initiatives at the University of California, Riverside, and Indiana University contend (McMurtrie 2016). Excessive centralization can threaten innovation and creativity that make our system work so well. Creativity in the research process requires decisions by those closest to the research issues themselves. Interdisciplinary units tend to shift power

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toward the center of the university, thus perhaps unintentionally promoting more centralized decision-making.

Once matters begin to span departments, the locus of control starts to shift upward, especially in grant-rich biomedical fields. The rotation of leadership of personnel in leadership positions risks repeated reorganization without sufficient time to fully reap whatever value these changes may have to offer. In other words, a decentralized system with a long time horizon has important strengths compared with a more centralized decision-making process that can sometimes reflect shorter-term decisions.

The final irony is that interdisciplinarity is likely to result in a more balkanized university. A great many cross-disciplinary research agendas are possible. Even if we limit our focus to applied concerns, there are in fact numerous fragmented aspects of any given practical social issue. For example, after the World Trade Center bombings, Pennsylvania State University sought out research grants in this area, and the result was 21 research centers devoted to homeland security. The interdisciplinary paradox is that the impulse to remove constraints on academic freedom rooted in disciplinary structures runs the risk of creating many more units and even greater constraints rooted in a more centralized university system.

3 Conclusion

Disciplines can be intellectually messy. They have roots in diverse intellectual traditions, complex internal structures, and fuzzy boundaries. Yet for all their difficulties, they nonetheless provide an organizational basis for instruction of undergraduates and graduates, certification of new scholars, selection of new faculty, and assessment of new findings. These roles are indispensable. Any viable vision of an interdisciplinary system relies on the continued existence and vitality of disciplines. Any vision of the modern university without disciplines would have to create functional equivalents for these functions. Reforms designed to promote interdisciplinarity should build on these strengths by building bridges between them rather than seeking to overturn the disciplinary system.

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CHAPTER 4

INTERDISCIPLINARY CASES AND DISCIPLINARY KNOWLEDGE

Epistemic Challenges of Interdisciplinary Research

WOLFGANG KROHN

This chapter provides a conceptual framework and determines the place of interdisciplinarity in the context of contemporary philosophy of science and social epistemology. It describes a widespread tension between the interdisciplinary commitment to complex real-world problems and the disciplinary strategies of designing and understanding simplified models. The epistemological challenge of interdisciplinarity is to relate knowledge about cases that are complex and singular with knowledge about concepts and causalities that are purified and general. While real-world problems call for highly specific and context-sensitive solutions, disciplinary problems serve as exemplars of a more general type. Finding solutions to real-world problems usually implies shaping a piece of reality in a satisfying way; solving disciplinary problems usually means having to find a sufficient causal explanation. What are the epistemological features of interdisciplinary research if it is supposed to serve the case as well as to advance knowledge?

4.1 Overview

The main propositions of this chapter are:

- Interdisciplinary research projects constitute a relationship between individual cases and more general knowledge bases untypical for disciplinary research.
- This relationship demands a new mode of knowledge, in which learning about a case is equally important as understanding causal structures. It calls for a combination of

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the "humanistic" ideal of understanding the individual specificities of just one case, and the "scientific" search for common features of different cases.

- Reflection on the character of interdisciplinary knowledge supports a critical reassessment of the received concept of scientific law and exemplary application.

If it is taken as a point of departure that most interdisciplinary research projects are organized around real-world cases, it is implied that these cases have to be understood with all their contingent features and circumstantial conditions. Each case is more or less different from every other case and has a certain value in itself. A paradigmatic example is global climate research. It aims at understanding the climate just exactly as it is, its origins and its future, in all its complexity and vagueness. Even if climate change is a broad topic, it is a unique one. It needs to be understood by means of a highly specific or even unique model to which many specialties contribute.

Interdisciplinary research also aims at cases that exist in several exemplars: cities and buildings in urban planning and architecture; prairies, sand dunes, or estuaries in restoration ecology and adaptive management; refugees in migration research; and prototypes in technological innovation. Here it seems possible to transfer knowledge gained in one case to similar cases. However, as discussed later, relying on similarities without respecting differences can be misleading. In any case, reference to real-world cases is the essential cognitive and political dimension of interdisciplinary research.

This approach deviates from other approaches in not attempting to define interdisciplinarity on the basis of and as a derivative of the disciplinary structure of knowledge. Rather it is assumed that real-world cases necessarily integrate heterogeneous knowledge bases, be these gathered under the institutional cover of a discipline or not. Any research field or research project that addresses real-world problems is considered to be essentially interdisciplinary. An advantage of this approach is its independence from unsatisfactory attempts to define institutionally or cognitively what a discipline is. In consequence, research fields that are rhetorically addressed as disciplines can be considered to be epistemologically interdisciplinary. Moran (2002) has nicely made this point with respect to the humanities—English, literary criticism, cultural studies, feminism, psychoanalysis, and the like. They are all interdisciplines, or disciplines with interdisciplinary features, because they tend to accept cases in their complexity and contingency. The same point was made earlier by Donald Campbell with respect to anthropology, sociology, psychology, geography, political science, and economics, which he called "hodgepodges" caused and shaped by real-world problems (Campbell 1969).

To start with real-world cases helps to understand certain features of interdisciplinarity. Later in this chapter the focus shifts from cases to processing contingency and complexity. The main interest is not to provide managerial and methodical solutions for cooperation between disciplines but to exploit the fruitful tension between understanding a case and searching for general knowledge. The main proposition here is that taking cases seriously implies a kind of learning considerably different from received views of inductive or deductive methods. Doing research in the context of real-world problems demands and develops skills and competencies that scholars are not used to.

4.2 Idiographic and Nomothetic Knowledge

What are "real-world" cases? The concept is meaningful only if contrasted with some "ideal world" of something. Every scientific experiment makes things simpler than they are, and theory imagines the world yet simpler. Historically, the paradigm was set by the invention of geometry. Since there is no *real* line, curve, or body that fits the demands of mathematical definition, they are ideally constructed. The ontological status of ideal objects has always been controversial, but this is not our point. The point is the epistemic change in hierarchical order. Real things, those which we can point at, are only approximations of ideal objects. The science of ideal objects is still called "earth measuring" (geometry), though there is not a single place on earth that fits its definitions. Sciences that do care for real-world measurement such as surveying, alignment, and mapping have developed methods able to determine any shape of an area. Limits to precision are not set by the methods but by changing and melting borders—as between land and water, forest and prairie, city and suburban sprawl.

Open boundaries present a very important issue in the analysis of real-world objects or systems. Geometry and surveying have fruitfully interacted in history. Surveying is real-world oriented and therefore is an interdiscipline. Geometry is a classical discipline (or subdiscipline, if mathematics is the discipline). Both come together in the earth sciences, in which on the one hand sites, events, and (hi)stories are important and on the other the objects, models, and methods of the lab. Frodeman (2003) has provided an epistemological analysis of the earth sciences showing how difficult it is to integrate the interdisciplinary strands into a coherent self-understanding of the discipline.

There are numerous other examples where, in a roughly identical segment of reality, strategies to grasp peculiar cases as they are coexist with strategies to construct cases as they are wanted for theory. The general proposition to be made with respect to this distinction is simply this: Interdisciplinary research is needed to focus on the peculiarities of given cases, while disciplinary research is characterized by substituting ideal features for given ones. Many modern research fields relate to both foci and are simultaneously driven by these two tendencies. They aim at becoming more of a discipline, as well as a place of integration for potential contributors from various disciplines. How this is balanced institutionally—in terms of journals, societies, handbooks, curricula, research sites—is of no concern here.

Call the specific features of a problem, a system, or a case its "idiographic component." And call the more general features gained by taking problems, systems, or cases as exemplifying or inducing a more abstract or idealized object of knowledge its "nomothetic component." The terminology was introduced by the neo-Kantian philosopher Wilhelm Windelband (1894). Idiographic literally means describing the peculiar, singular, and specific.[1] Nomothetic literally means setting the (scientific) law. The law-like quality of scientific knowledge is associated with certain features such as the reproducibility of experimental facts, prognosis of events, general validity of propositions, and causal explanation of correlations. Even if the definition and relation of these epistemic features are controversial, they undoubtedly strengthen the difference between something one happens to know and

[1] The likewise usual wording "ideographic" does not refer to Greek *idios* = peculiar, but to idea = form, Gestalt, which is no less appropriate.

theoretically corroborated knowledge. The ideographic structure of knowledge Windelband believed to be best exemplified by historiography. A historian who specializes in the founding of the United States of America usually does not wish to become a specialist for foundations in general, but builds his reputation on knowing everything about just this case and giving it an original and surprising interpretation. If he cared to analyze another founding—say of the Roman Empire, Brazil, or the European Union—neither factual knowledge nor interpretation schemata can be transferred from one to the other.

When Windelband introduced this terminology he was not only a famous philosopher but also rector of Strasbourgh University. He found himself in a position to reconcile a heated controversy between the natural/technical and the cultural sciences/humanities. The rapid ascent of the natural sciences led to claims that true knowledge would only reside in laws. Eventually all knowledge fields including the humanities were to be converted into law-seeking disciplines. The counterattack aimed at the assumed weak point that natural sciences are completely unable to develop a coherent understanding of something as complex as a culture and its history, or even some part of it, such as a specific city, not to mention art, literature, and religion.

In his presidential lecture in 1894, Windelband suggested equal rights to both forms of knowledge. Knowledge production is guided either by an interest to identify laws, which implies turning things into variables, or by an interest "to describe as complete as possible a singular event or chain of events spread over a limited time." Examples of events worth scholarly interest are, according to Windelband, "Actions of a person, the character and life of a single man, or of an entire people, the character and development of a language, a religion, a legal order, of a product of literature, art, or science: and each of these subjects demands a treatment corresponding to its peculiarities" (Windelband 1907, p. 363). For Windelband, the distinction is not built on different classes of objects—natural events versus human affairs—but on methods. In principle, everything can become the object of a nomothetic as well as idiographic analysis. His examples are language, physiology, geology, and astronomy. If objects in these fields are considered in their specificity, "the historical principle is carried over to the realm of the natural sciences" (Windelband 1907, p. 365). If the objects are taken as types or exemplars, the methods of the natural sciences apply.

By the traditional views of philosophy of science, it seems obvious that the sciences should search for laws, principles, and other forms of generalized explanations. It is less obvious why they should care for singular or even unique cases. Windelband assumed their relevance with respect to cultural heritage, identity, and value. Admittedly, one can never know in advance whether or not a single case turns out to be culturally relevant. But if it were considered to have no potential value at all, research would not be started. Or put in a more constructive language, a scholarly effort to study a case automatically attaches some sort of value to it. Windelband's neo-Kantian disciple Rickert offered the following equation: "There is not only a necessary connection between the *generalizing* and the *value-free* observation of objects, but also an equally necessary connection between the *individualizing* and *value-laden* perception of objects" (Rickert 1924, p. 58). Even if this general statement may be doubtful, obviously all real-world problems have a value dimension, be it economical, social, cultural, or environmental. Windelband and Rickert chose historical research as their paradigmatic field because the preservation of cultural goods and values seemed to be even more important in a society that became exposed to dramatic industrial changes. Today we would add to the historian's work pressing problems caused by misguided developments.

Real-world problems are problems because values are at stake. Solutions are only accepted if they address these values.

Concern for idiographic cases does not invalidate more general knowledge. Usually, interdisciplinary case studies are expected not only to solve single problems but also to contribute to stocks of knowledge. However, the epistemic structure of these stocks of knowledge is different from knowledge condensed in theories or paradigms. The relationship between ideographic and nomothetic orientations of interdisciplinary research needs to be analyzed and interpreted in a new way. The first step will be to better understand the nature of cases by looking at variants of the so called case-study method practiced in professional schools. Certainly, higher education of professionals and experts aims at goals different from doing research. However, the reasons why the case study method seems to be successful in professional training are important for understanding how cases contribute to interdisciplinary knowledge.

4.3 Learning Based on Case Studies

The methodology of using case studies in educational programs originated in the pioneering achievements of the Harvard University professional schools. As early as 1870, the Harvard Law School shifted the study of law from the classical systematic approach to the analysis of cases. In 1920, the Harvard Business School developed a new curriculum based on case studies. In 1985, the Harvard Medical School followed suit with its New Pathway Program, which was considered revolutionary within the field of medical training. The following presentation is concerned not with an evaluation of this educational method, but rather with the question of what can be learned from individual cases.

David Garvin—himself a faculty member of the Harvard Business School—emphasizes the three dominant goals of case study methodology: "learning to think like a lawyer"; "developing the courage to act"; "fostering a spirit of inquiry" (Garvin 2003, subheadings). Competencies from three professional fields merge here: the logical expertise of a lawyer, the decision-making capacity of a manager, and the curiosity of a researcher. Cases that have been of paradigmatic importance for the development of laws are not central to the training at the Harvard Law School. The focus is rather on those cases that are controversial within the legal profession, those that were wrongly decided or were revised. Garvin cites another member of the faculty who notes, "We have conflicting principles and are committed to opposing values. Students have to develop some degree of comfort with ambiguity" (Garvin 2003, p. 58). The analysis of individual cases frequently does not lead to a clear result. "Students often leave class puzzled or irritated, uncertain of exactly what broad lessons they have learned" (Garvin 2003, p. 59). On the contrary, they learn that general legal doctrines are rarely unambiguously applicable and that the smallest distinctions can play a role in their application. Furthermore, these cases help students practice dealing with unknown and unforeseen circumstances, with varying conditions, and with surprises.

The description of Stanford Law School's "case study teaching method" is similar to Harvard's: "Case studies and simulations immerse students in real-world problems and situations, requiring them to grapple with the vagaries and complexities of these problems in a relatively risk-free environment—the classroom" (Stanford Law School 2015). Far from introducing individual cases in Kuhn's sense as paradigms, these are examined as unsculpted and uninterpreted as possible. This methodology is thus quite suitable to an academic policy that places value on the grasping of complex configurations, on the identification of possible action, and on the assessment of consequences. It aims at an interdisciplinary training portfolio: "Students identify for themselves the relevant legal, social, business, and scientific issues presented, and identify appropriate responses regarding those issues" (Stanford Law School 2015).

Education at the Harvard Business School is also guided by the principle that greater competence can be acquired through constant rehashing of case studies than through studying theoretical and methodical knowledge and the intended applications thereof. Underlying the choice of these individual cases are the following criteria:

> Typically, an HBS case is a detailed account of a real-life business situation, describing the dilemma of the "protagonist"—a real person with a real job who is confronted with a real problem. Faculty and their research assistants spend weeks at the company. . . . The resulting case presents the story exactly as the protagonist saw it, including ambiguous evidence, shifting variables, imperfect knowledge, no obvious right answers, and a ticking clock that impatiently demands action. (Harvard Business School, 2008; for a more recent account, see Harvard Business School 2015)

The students are presented with about 500 of these cases in the course of their studies, the main goal being to school their decision-making behavior. The large number of cases is not seen as an inductive basis for statistically generalizable knowledge, but rather as preparation for a maximum number of diverse situations. In addition to these cases studies, the program offers courses in "analytical tools." The following list of academic goals is presented in Garvin (2003):

- training of diagnostic skills in a world where markets and technologies are constantly changing
- assessment of the ambiguity of constellations
- consideration of the incompleteness of the information at hand
- recognition of the existence of a multitude of possible solutions
- preparedness to make decisions in the face of uncertainty and time pressure
- development of persuasive skills. Management is a social art; it requires working with and through

From a critical perspective, the tendency to quick decision should be noted. "The case method does little to cultivate caution. . . . Students can become trigger-happy" (Garvin 2003, p. 62). For a more balanced view, see Srikant et al. (2009).

Inaugurated in 1985, Harvard Medical School's New-Pathway Program has supplanted the classic basic training in medical fields and has with some delay affected applications at the sickbed. It also highlights the point that every single case is self-contained. To cite Tosteson, the program's founder, medicine "is a kind of problem solving" and each medical encounter is "unique in a personal, social and biological sense. . . . All these aspects of uniqueness impose on both physician and patient the need to learn about the always new situation, to find the plan of action that is most likely to improve the health of that particular patient at that particular time" (Tosteson, cited in Garvin 2003, p. 63). Since then, the program underwent several revisions, seeking the optimal combination of disciplinary knowledge development and practical responsibility for the individual case.

Further examples of curricula that have adopted the case method entirely or partially include engineering, sociology, psychology, education, architecture, and economics. What constitutes its success if not superiority in higher education? The most notable criterion is its insistence on the individuality of cases. They are not cases in point, not exemplars of a type—at least not in the first place. The didactic concept is not to present a general structure via a number of examples, whose special features quickly retreat behind the emerging abstraction. No case can be exchanged for another, since something different is learned from each case. Concentrating on the idiographic nature of each case means to develop a sense for its details and the seemingly incidental aspects that make it special. Every case study of this kind is unavoidably connected to deficits in information, to ambivalent interpretations, and to the risky effects of possible interventions.

At variance with more traditional academic education, the focus is on grasping both the differences and the similarities between cases. Identifying case-specific gaps in knowledge is as important as applying knowledge gained from other cases. The background philosophy seems to be that professional realities are not determined by general rules or even scientific laws, but are constituted by a vast network of particular cases. The competency of the professional consists in deriving operative gain from comparing similarities and differences between cases.

Traditionally, the two pillars of scientific methodology are inductive generalization leading to theory and deductive specification via application to cases. Here, however, neither is applied. Rather, both are substituted by the expansion of a network of cases, in which the mesh density of analogous relationships is continually tightened. Does this indicate a third path that avoids the alternative between generalization and specification? Does such professional training develop a learning core not contained in the traditional theories of the growth of knowledge?

4.4 Knowledge and Skills: The Professional Perspective

The launching point for the educational programs described in the previous section is the shortcoming of academic training with respect to professional competencies. The criticism is that the academy is unable to deal with the complexities of true life, but must reduce these in accord with theoretical concepts. Academic training follows the paradigm of alternating theoretical construction and experimental research by which the object of study is subjected to the ideal conditions of the laboratory. This is not the reality that the professional expert confronts.

The case method cultivates certain capacities that are most often termed "skills." Skills do encompass rational pieces of knowledge, but equally important are routines, habits, and trained intuitions, all of them are not completely explicable components. They come into play not only for professional know-how, but in many fields of learning like the acquisition of crafts and trades, doing sports, or mastering a musical instrument. More generally, all techniques that require the coordination of physical training with the comprehension of rules and readiness to act are based on skills. Here the study of introductory books and instruction manuals helps little. The observation of masters helps a bit more.

Decisive, however, is the continual exercise of physical practices until these become routine. Situational assessment, spontaneous coordination of action, and a repertoire of strategies are all conditions for success. The important point in our context is this: Even when skills have been developed, each individual case retains its particular meaning. There is no overarching level of competence comparable to theoretical knowledge, in which skillful action could be adequately reconstructed as theoretical objects. Although there have been attempts in the scientific analysis of sports and music to construe such levels, what ultimately count are skills in action.

The Harvard method and the teaching methods practiced in the fields mentioned above have in common the accumulation of analogies between related configurations, whereby it is as important to attend to differences as to similarities. In this way, the learner knots together a network of configurations that is fed by individual cases and used for situating further cases. This is what defines the professional expert (e.g., the lawyer, doctor, or manager), the specialized expert (e.g., the craftsman, athlete, musician), and even, if one can say so, the everyday expert (e.g., the habitual walking in uneven terrain, parenting, driving). It may be assumed that in the background of the case method a much deeper mechanism of analogical reasoning is at work, which Hofstadter and Sander (2013) have called the "fuel and fire of thinking." By the same token, analogical reasoning enables us to categorize as well as differentiate the world and makes us experts when we apply it and scale it up.

It is beyond this chapter to explore cross-links between the case method and Hofstadter's model. As applied to interdisciplinary research, one can conclude that learning from case studies is suited primarily for expanding the professional know-how of experts. In keeping with the traditional concept of professions, one could coin the term "professional researcher." Such a professional would be an expert in the investigation of open problems in contingent and complex individual cases, which occur within a certain domain of action. Their expertise is based on a network of experiences gathered and expanded case by case. From a scientific point they are not less equipped with disciplinary knowledge the use of which makes them professionals. As real-world cases usually call for several disciplinary competencies, interdisciplinary cooperation between professional experts is required for this type of research.

One of the best analyses of the design of case studies in sociology (inspired, by the way, by the Harvard methodology) confirms this grounding of research in expertise. "Common to all experts is that they operate in their fields of expertise on the basis of an intimate understanding of many thousands of concrete cases. Context-dependent knowledge and experience constitute the core of expert praxis. . . . Only through experience in dealing with cases can one develop from a beginner to an expert" (Flyvbjerg 2006, p. 222). Based on Aristotle, Flyvbjerg has developed a conceptual frame that relates three categories of doing research—the epistemic approach to universal knowledge, the technical approach to functional know-how, and the social approach to phronetic judgment or practical reasoning. As is demonstrated in several case study reports, the successful solution of complex societal problems presupposes the operative use of the three sources (Flyvbjerg et al. 2012).

4.5 Individual Case and Epistemic Knowledge

The idiographic aspects of interdisciplinary research have now been sufficiently explored. It was important to begin with these, as they are quite removed from standard philosophy of science and from learning theories of higher education. However, to end with the case method would mean to declare theory based epistemic knowledge a needless encumbrance. The important point was that sensitivity to cases cannot be derived from theory. This does not imply that theory cannot contribute to understanding cases, nor that cases cannot advance theory. The statement that contingency in interdisciplinary research cannot be eliminated gains its epistemological value only because important resources of knowledge can be tapped into, whose validity and applicability are accepted, even if they do not suffice to grasp all details of a specific case.

4.5.1 Individual Cases and Unconditional Laws

The relationship between the specification of causal knowledge toward individual cases and the generalization of on-site findings appears at first sight to be that between a deductive strategy of applying substantiated knowledge and an inductive strategy of developing hypotheses for new knowledge. But this distinction does not allow the methodological challenge of interdisciplinary research to come to light. The challenge is to balance the tension between understanding a case in its real-life context and contributing to a stock of theoretical knowledge. This section relates this tension to current discussions in philosophy of science.

In her influential book *How the Laws of Physics Lie* (1984), Nancy Cartwright presented the thesis that the fundamental laws of physics hold true only for highly idealized theoretical objects that do not exist in the real world. Strictly interpreted, these laws are false when taken as empirical descriptions of reality. The well-known example is that of Galileo's Law of Falling Bodies. Its real-world validity is modified by friction, wind force, raindrops, and the shape of the body. Cartwright loves to illustrate the problem by an example already used by the Vienna Circle philosopher Otto Neurath (Cartwright 1999, p. 27): the calculation of the trajectory of a bill dropped from St. Stephan's dome in Vienna. Even the joint forces of mechanics, fluid dynamics, and computer simulation methods would not come close to a correct prediction.

From a pragmatic point of view, Cartwright's objection seems to be of no effect. In the laboratory objects are stylized to better fit theory, and theorists acknowledge practical limitations to the absolutely perfect realization of causal assumptions. Within these limits, knowledge can be put to work. From a philosophical perspective, however, her thesis continues to provoke unrest. If under close scrutiny universal laws have no empirical content, then the project of interpreting reality through reductionism remains ungrounded. At best, it can be played through for simple cases from which one cannot extrapolate, what Cartwright called "the dappled world" (1999). This world can be scientifically captured only by a broad variety of laws with limited range and with no consistent logical order. In describing this world we can better speak of capacities, tendencies, and potentialities than of rigid laws. Recently Cartwright and Hardie have applied her philosophy to the risks of transferring policy projects. "It is a long road from 'it works somewhere' to . . . 'it will work here'" (Cartwright & Hardie 2012, p. 6).

Cartwright's strong statement regarding the presence, if not predominance, of the idiographic in the scientific description of the world is highly controversial (see Earman et al. 2002). It has challenged the privileged position of the concept of natural law as the standard and compass for scientific theorizing. Moving beyond Cartwright's proposal, Giere (1999) suggested that the concept of law should be completely struck from the language of philosophy of science. He is of the opinion that we cannot rid ourselves of the theological origin of the concept. Only God as the external legislator of the world would be in the position to command by general rules completely obedient natural things. Since the Kantian project of anchoring fundamental laws in the structure of reason failed, for Giere no further candidate remains that could guarantee the universality and necessity of the laws of nature. In Giere's reconstruction, lawful regularities become systems of equations that pertain, not to reality, but rather to imaginary models created for their verification—an idea for which Cartwright coined the term "nomological machine." Real-world constellations cannot be grasped precisely.

Whether, despite these objections, it will remain meaningful to speak of general and unconditional laws of nature can be left an open question here. It suffices to ascertain that the classical notion of a law's universal validity no longer fully captures the "cases" that fall within the law's domain. The take-home message of this philosophical discussion concerning the relationship between the nomothetic and idiographic in science is that the tension between universal validity and exemplary cases is already contained within the unconditional laws of physics.

4.5.2 Individual Cases and Conditional Laws

Some laws of physics still possess the elevated status of being general. Laws typical for sciences as biology, psychology, and economics are burdened from the beginning with the acknowledgment that their predictions and causal explanations are valid only under specific conditions or to a certain degree. The two central problems of such laws are that (1) the respective specific conditions cannot be listed completely and definitively and (2) exceptions to the rule can always be included in the collection of excluded conditions. The difference with regard to the laws discussed in the above section is this: General laws such as the mutual mass attractions, the conservation of energy, and entropy are considered unavoidably and eternally valid, even if the calculation of concrete cases is difficult or impossible. For conditional laws such as Mendel's laws of heredity genetics, the law of diminishing return in economics, or the Gestalt laws in psychology, the lawful connections are defined for objects whose uniformity, continuity of existence in time, and independence from their environment are not guaranteed.

Following in the footsteps of the evolutionary biologist Stephen Jay Gould, Sandra Mitchell asserted the following for biological regularities: "If we rewound the history of life and 'played the tape again', the species, body plans, and phenotypes that would evolve could be entirely different. The intuition is that small changes in initial 'chance' conditions can have dramatic consequences downstream. . . . Biological contingency denotes the historical chanciness of evolved systems, the 'frozen accidents' that populate our planet, the lack of necessity about it all" (Mitchell 2002, p. 332). Conditional laws can be investigated only in tandem with the historical development of the objects and their contingent context. In this manner, the idiographic is officially granted entrance into the grasp of the law-like generalization under consideration. The conjecture of a conditional empirical law usually emerges with the reservation that intervening contingencies are to remain irrelevant (the ceteris paribus clause). If and when they do become relevant, the question must be confronted whether they dissolve the assumed law or alter the set of conditions. An exhaustive philosophical discussion of the ceteris paribus topic and its implications on the idea of law-like knowledge can be found in Reutlinger et al. (2014).

It is possible to reinterpret the epistemological problem of the validity of contingent laws as an answer to the question of how the tense relationship between the nomothetic and the ideographic can be combined. Within the realm of biological research, it is as productive to search for conditional laws as it is to identify configurations of restricted validity. It is as interesting to reduce contingency through ceteris paribus clauses—expanding the effective domain of a law, as it is to increase contingency—thereby pursuing the relevance of configurations not yet understood. Mitchell writes:

> In systems that depend on specific configurations of events and properties, . . . which include the interaction of multiple, weak causes rather than the domination of a single, determining force, what laws we can garner will have to have accompanying them much more information if we are to use that knowledge in new contexts. Thus the central problem of laws . . . is shifted . . . to how do we detect and describe the causal structure of complex, highly contingent, interactive systems and how do we export that knowledge to other similar systems. (Mitchell 2002, p. 335)

It is in this manner that the analysis of the concept of law within these specific sciences approximates learning from case studies.

4.5.3 Individual Cases and Ideal Type

The diverse efforts within the social and historical sciences to formulate diachronic and synchronic generalizations have never led to results that are in any way comparable with the status of the conditional causal laws in the natural sciences. The only exception is in modern economics, which since its origins in the eighteenth century has attempted to formulate qualitative laws (like, for example, Marx's law of falling profits) and quantitative laws of market behavior (starting with Leon Walras). All such attempts remain controversial within the economic sciences and even more as applied to political economy. In the other social sciences (such as historical sciences, cultural anthropology, sociology) a more skeptical view prevailed. Despite this, generalizations of some sort are still being considered.

For example, the concept of "ideal type" developed by Max Weber has gained widespread recognition. Weber formulated this concept in the context of the ongoing discussion of Windelband's and Rickert's ideas (Oakes 1987). His goal was to justify that social sciences can as well search for objectively valid and controllable propositions as attempt to understand highly specific and complex constellations in which elements of culture, politics, religion, and economics merge. In Weber's words, an ideal type

> is a conceptual construct which is neither historical reality nor even the "true" reality. It is even less fitted to serve as a schema under which a real situation or action is to be subsumed as one *instance.* It has the significance of a purely ideal *limiting* concept with which the real situation or action is *compared* and surveyed for the explication of certain of its significant components. . . . In this function especially, the ideal-type is an attempt to analyze historically unique configurations or their individual components by means of categorical concepts. (Weber 1949, p. 93)

4.6 Conclusion

The preceding analyses of the relationships between law-like universality and concrete case support the conclusion that this rapport may indeed be fraught with tension, but that it thereby in various ways contributes to the scientifically rooted description and construction of reality.

The goal here has been to integrate nomothetic potential and idiographic description into a model that correlates a causal explanation of reality (nomothetics) with the situational, local specifics of a case (idiography) as far as possible. In closing, this point can be briefly illustrated using the example with which this chapter began. Modern research into the effects of climate change has taken the form of a giant worldwide project. It forces the participating researchers to comprehend the singular, extraordinarily improbable case of Earth's climate in its specific state and its developmental dynamic. This is an extremely idiographic situation. Enormous constraints arise from being tied into a heterogenic configuration of political and scientific actors—the Inter-governmental Panel on Climate Change, whose ultimate goal is not cognition, but rather the science-based coping with climate change.

The background for this effort is the consensus that a certain state of climate constitutes a principle value for life on Earth. From this idiographic value component (in Rickert's sense), it follows that research into the effects of climate change does not only deliver analysis and prognosis, but also participates in articulating local and global strategies for controlling and adapting to climate change. The interdisciplinary goal is fitting the singular case of Earth's climatic dynamics into the most widely accepted simulation model. The unique dynamics of the individual case has been translated into the unique dynamics of the model (compare Lenhard et al. 2007). The research is integrated into social transformation while it is being carried out, even though its conclusive end results are still out of sight. This merger of research and innovation seems to become a decisive characteristic of the so-called knowledge society. Interdisciplinary projects play a leading role in it.

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CHAPTER 5

THE MILITARY-INDUSTRIAL ROUTE TO INTERDISCIPLINARITY

STEVE FULLER

This chapter considers from both a historical and philosophical standpoint the role of war and commerce in motivating interdisciplinary research, typically against the "normal science" grain of academia. This kind of interdisciplinarity is best described as "use-inspired basic research," which makes creative use of synergies between relatively uncommunicative academic literatures, or "undiscovered public knowledge." Moreover, both academic researchers and administrators have been attracted to such research for its clear, albeit often contestable, goal orientation, the "cult of success," as discussed below. The Rockefeller Foundation and DARPA are the two major institutional exemplars of this form of interdisciplinarity, which is fairly described as "Mode 2" or "triple helix" knowledge production. The chapter stresses the adventurous, indeed "creatively destructive" character of this research, which typically leaves a lasting impression on both academia and society as a whole—be it for good or ill. In this context, the career of Fritz Haber—a man steeped in not only philosophy and the physical sciences but also war and commerce—is considered as exemplifying the Janus-faced character of this type of interdisciplinarity.

5.1 Introduction: The Military-Industrial Antithesis to Academia

"Academic freedom" may be the pursuit of truth wherever it may lead, but it is not obvious that left to their own devices academics will necessarily explore, let alone exploit, all that is knowable to the fullest possible extent. Put more provocatively, the university is inclined to compromise its own liberal universalism, unless compelled by external forces. Perhaps the two most historically important countervailing forces to this tendency to compromise—the external drivers of academic universalism—came together in the twentieth century in what US President Dwight Eisenhower called "the military-industrial complex." To be

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sure, this claim is both controversial and counterintuitive. After all, the military and industrial sectors of society are generally portrayed as inhibitors or distorters of pure academic inquiry. However, this depiction is misleading. Nevertheless, it has skewed the narratives that historians have told about the development of the sciences, resulting in a neglect of what Donald Stokes (1997) has called "Pasteur's Quadrant," namely, basic research that is use-inspired.

For our purposes, use-inspired basic research is best seen as a form of what Fuller (2010) calls "deviant interdisciplinarity," whereby the interdisciplinarian does more than merely combine the fruits of mature disciplines. Rather, she redirects disciplinary development in acts of higher-order knowledge integration, which in turn point to some overarching epistemic ends, typically to do with the amelioration of the human condition. Thus, deviant interdisciplinarity presupposes a more "interpenetrative" attitude to disciplines, one that sees their boundaries as porous and movable. The natural enemy to the approach described here is that of Kuhn (1970), which identifies the rigor and focus of science with the closed intellectual borders policy of a disciplinary "paradigm" (Fuller 2000). Unsurprisingly, an early attempt to turn Pasteur's Quadrant into the explicit mission of state-based science policy was the Habermas-sponsored German "Finalization" movement of the 1980s, which was crafted as an antidote to the problem of diminishing returns on paradigm-based research investments (Schaefer 1984).

The phrase "Pasteur's Quadrant" recalls that Louis Pasteur's enduring achievements in what is now called microbiology involved bringing together knowledge from different academic disciplines, typically by challenging one or more of their fundamental assumptions. As witnessed in Pasteur's lifelong "Franco-Prussian" rivalry with Robert Koch, his efforts were in aid of solving major practical problems relating to the national interest in commerce and war. Nevertheless, these efforts are claimed by academia today as having been "biomedical" in nature. Here the normative term "disease" serves as a pivot to convert Pasteur's achievements from "applied" to "basic" research. Thus, his original attempts to stop bacteria from destroying the silk, milk, wine, and beer industries or killing troops in the field are now seen as proper "scientific discoveries" in the disciplines of biology and medicine.

The guiding epistemological intuition for what follows is that the persistence of deep practical problems (i.e., ones that address the human condition as such and do not simply take care of themselves over time or can be resolved in endlessly ad hoc ways) are more about the organization of academic knowledge, which prevents the right connections from being made, than about anything mysterious in reality itself. In the library and information science literature, this failure to connect literatures properly results in large amounts of "undiscovered public knowledge" (Fuller 2015, p. 31). It is sometimes used to explain why so much attention is lavished on such a relatively small portion of the scholarly literature, perhaps along the lines of Vilfredo Pareto's 80/20 principle (i.e., 80% of the actual effects are due to 20% of the available causes). When Pasteur famously claimed that discovery favors the prepared mind, he was alluding to a mind that was uninhibited by academic prejudice and hence open to a broader range of reality—including the 80% that is already out there but routinely gets overlooked.

That academia might be a source of such prejudice goes back to Francis Bacon's critique of the medieval scholastics as purveyors of "idols of the mind." The history of the modern university, starting with Wilhelm von Humboldt's rectorship at the University of Berlin in the early nineteenth century, can be understood as an attempt to recover from Bacon's spin on academics as inhibitors rather than promoters of learning, since we know now—and Bacon probably knew back then—that the medieval scholastics who were members of the Franciscan order (e.g., Robert Grosseteste, Roger Bacon, Bonaventure, Duns Scotus, William of Ockham) pioneered both the turn of mind and the turn to experiment that Bacon himself championed (Fuller 2015, chap. 2). Nevertheless, Bacon stereotyped the original academics as being reliant on only one of the two books through which God communicated with humanity: the Bible—but not Nature. To be sure, the stereotype did capture how scholasticism was generally understood, insofar as that merely contradicting biblical authorities set Bacon's contemporary Galileo at odds against the Catholic Church. Nowadays economists would diagnose the increasingly esoteric trail of scholastic biblical commentary as symptomatic of a "path-dependent" and "rent-seeking" academic culture, whereby once you have discovered a source of truth (in this case, the Bible), you make it difficult for anyone else to seek truth unless they do it your way. It provided the context for the original attacks on technical language ("jargon") as obscuring rather than illuminating thought (Fuller 2002, chap. 1).

In the Enlightenment, Bacon's perspective on university life was adopted with gusto, resulting in several schemes to reorganize academic knowledge in the name of human emancipation from established authority. In particular, much play was made of Bacon's own proposal to base the division of disciplinary labor on our mental faculties in order to maximize their spontaneous synergies (Darnton 1984, chap. 5). Because Bacon and his Enlightenment followers remained convinced of humanity's divine lineage, they were confident that only the blinkered nature of other humans—namely, the clerics who controlled the universities—stood in the way of an indefinitely well-informed and prosperous future. After all, even though discoveries are advertised as instances of nature revealing itself anew, it is usually not too difficult to find one or more precedents for the discovery in neglected writings from the past. Admittedly, each of these past accounts may be partial, but if the right combination of them had been made, then the innovation could have been inferred. This may suffice as an operational definition of a "prepared mind" for scientific discovery, in Pasteur's sense. In that case, the "discovery" is simply a high-tech version of Plato's *anamnesis*, whereby, say, an experimental outcome prompts us to recall what we already implicitly know.

With hindsight, we might say that the problem resides in the universities of the seventeenth and eighteenth centuries being primarily glorified professional schools dedicated to reproducing society's governing class—that is, law, medicine, and the clergy. These professions were, in the first instance, the bastions of continuity against any forces of change. It was left to Humboldt to exchange the university's traditionally inertial image for a more dynamic and progressive one. Nevertheless, the original Baconian suspicions have continued to be channeled in the various "military-industrial" attempts to shape the academic agenda. It is worth stressing that the spirit of the attempts that we explore in the rest of this chapter is one of recovering epistemic riches that academics themselves have produced but have either neglected altogether or squandered on increasingly parochial projects (aka "normal science"). In other words, the military-industrial approach to interdisciplinarity is more about confronting the academic mind-set—its own biases and limitations—than academic knowledge per se. In this respect, the military-industrial approach may be seen as an intentionally ad hominem attack on academics.

5.2 The Cult of Success and the Military-Industrial Will to Knowledge

The state of mind required for knowledge started to undergo a significant transformation in the Christian era, which continued into secular modernity. The Greeks believed that "knowledge," in the sense of a systematic understanding of how things hang together, was available to all educated people with sufficient leisure at their disposal. The relevant mental states included Platonic contemplation of the cosmos and the receptive observation of nature promoted by Aristotle. Notably absent was the idea of a *journey*, let alone one whose destination is at best partially understood in advance and may not even be reached by those who start the journey. Nevertheless, this idea, common to both Christian eschatology and secular progress, continues to inform the collective psychology required for justifying science as an intergenerational social enterprise of indefinite duration (Passmore 1970, chaps. 10–12; Fuller 2015, chap. 3). The military-industrial "will to knowledge" puts a premium—perhaps more so than academics—on reaching a satisfactory conclusion to the epistemic journey.

That academics are inclined to stress the virtues of the journey over its destination may be dubbed the "Curse of Kant"—the academic reluctance if not incapacity to specify an end to inquiry that would count as a meaningful conclusion to those engaged in it. Instead, academics tend to provide "regulative ideals," à la Kant himself, which specify little more than an orienting posture to inquiry or, à la logician Alfred Tarski, "truth conventions," which identify conditions that need to be met for "truth" (the name given to the end of inquiry), while saying nothing about how those conditions might be met. Missing from all this is a strong sense of *success*, which is central to the military-industrial will to knowledge. Success implies that a journey has ended in a way which vindicates its having been taken. In this concrete sense, the end will have justified the means. Here it is worth recalling that "the ends justifies the means" was originally a theological slogan to justify how all the evil in the world contributes to the realization of divine creation. Kant was a sworn enemy of this way of thinking, but less on ethical than on epistemological grounds: If God's existence cannot be proven, then trying to think like God is idle—and potentially dangerous—speculation that ignores something that is already known, namely, human finitude.

In contrast, the military-industrial will to knowledge adopts a standpoint that was openly defended two generations after Kant by such left-wing followers of Hegel as Ludwig Feuerbach and Karl Marx. It takes "God" to be simply the name of the successful conclusion of the project of human self-realization. In that case, any obstacles in the way to getting "what we want" (however defined) is taken more in the spirit of a challenge to be overcome than a sign of limits that should not be exceeded. This line of thinking, which had explosive political consequences in its day (i.e., the 1848 liberal revolutions), was encoded in philosophy's DNA by the German-trained Scottish philosopher who introduced "epistemology" into English, James Ferrier (Fuller 2015, p. 34). As if in anticipation of Wittgenstein's *Tractatus*, Ferrier argued that if the world can be divided exhaustively into what is "known" and what is "unknown," it follows that everything is knowable, which means that the very idea of "unknowable" (e.g., Kant's *noumenon*) is nonsensical. The "unknown" is simply the "yet to be known." (This applies equally to the "unknown unknowns," more about which below.) In this way, a much more concrete and explicit sense of the ends of inquiry—a successful conclusion to a strategy that one might design and execute—is licensed, which in turn has served to propel the military-industrial will to knowledge over the past 150 years.

However, the "military" and the "industrial" sides of this intellectual complex have paradigmatically different ways of interpreting "success." The difference is illustrated in two senses in which we might achieve the "truth," understood as the concrete ends of inquiry. We might mean either something to which one gets closer or something that grows over time, an "intensive" or an "extensive" magnitude: the former measured, the latter counted. Thus, one speaks of either "approximating the truth" or "accumulating truths." That is the difference between "military" and "industrial" approaches, respectively (Fuller 2002, Conclusion). The former is mainly about how to make up the distance from a goal, the latter about how to expand so as to incorporate—or crowd out—all other competitors, which is itself constitutive of the goal. Thus, two conceptions of success loom: *victory* in war and *monopoly* in commerce, the one materializing the correspondence theory of truth, the other the coherence theory of truth. Capitalism plays a distinctive role in this dialectic, with its fixation of *productivity*, which is not only about producing more stuff, in this case, knowledge (industrial) but also producing it more efficiently, which may mean abandoning or destroying past practices (military). It was just this dual feature of capitalism that led nineteenth-century socialists—not least Marx—to envisage a less labor-intensive future, courtesy of new technology, which meant that most people would live either in leisure or poverty, depending on what Marx called the "social relations of production."

The military-industrial will to knowledge is clearly *antidisciplinary*, but how it is *interdisciplinary*? It is antidisciplinary by virtue of its denial that there is something "natural" about the origin and maturation of disciplines. Thus, the military side would hasten knowledge production, capitalizing on whatever urgency might focus minds on overcoming a common foe, whereas the industrial side would scale-up knowledge production, enabling it to escape the laboratory and permeate the life-world. From this dual standpoint, the organic "no science before its time" approach to inquiry championed in Kuhn (1970) looks like a mystification of the history of science. Indeed, rather than tending to disciplines as protected species in an academic ecology, the military-industrial will to knowledge treats them in the manner of plant and animal husbandry, open to the mixing and matching of knowledge from multiple disciplines to improve the human condition. The aftermath of the Franco-Prussian War of 1870–1871 had demonstrated how the exigencies of war can incentivize advanced industrial economies to streamline production processes, distribution networks, and accelerated innovation. The US-based Carnegie Endowment for International Peace, for the past century one of the world's most influential think tanks, funded the Vienna Circle founder Otto Neurath and the British economist John Maynard Keynes to explore the matter in light of the Balkan Wars and World War I, respectively.

Although by disposition Neurath was a socialist and Keynes a liberal, both recognized that the perceived threat of war strengthened the state's hand in providing incentives for industry to alter its default patterns of behavior in more socially beneficial ways—not least the retention of novel interdisciplinary working arrangements forged in wartime. This is what the mastermind of the Prussian victory in the Franco-Prussian War had called the state of "permanent emergency," more about which below. In the middle third of the twentieth century, economics provided the main disciplinary arena for concretizing this vision. The venue was the Cowles Commission, named for the owners of the *Chicago Tribune*, which by the 1950s had successfully promoted econometric modeling—the prototype for today's computer simulations—across the ideological spectrum of economics, not only the Keynesians, but also the Soviets (via Oskar Lange's market socialism) and even neoliberal capitalists (via Milton Friedman's monetarism). At the time, this development was seen as having moved economics decisively away from its classic "free market" base, the sense in which Friedrich Hayek might be seen as the natural heir of Adam Smith, since Cowles clearly took a *dirigiste* approach to the economy—that is, as something that might be controlled as a machine, *Homo economicus* rendered cyborg (Mirowski 2002, chap. 5).

At stake here was whether human creativity, the source of the entrepreneurial spirit, could be simulated in some systematic understanding of economic life. Among Cowles's biggest opponents were Adam Smith's self-appointed US descendants, most notably Frank Knight, who started the Chicago School of Economics. Knight rejected Cowles's top-down approach in favor of something "spontaneously generated" but also mysterious; hence, Knight influentially distinguished between states of ignorance due to "uncertainty" proper (i.e., where no probability can be assigned because of the event's unprecedented nature) and to "risk" (i.e., where probability can be assigned because the event has precedent). The former was the realm of the entrepreneur and the latter that of the manager. For this reason, Knight held that the use of mathematics in economics would always be restricted to routine ("manageable") economic behavior but not the creative part, a claim similar to one often made about the limits of experimental psychology in understanding human creativity.

However, Knight failed to anticipate how mathematical models would radically transform thinking about uncertainty. It amounted to the management of "unknown unknowns," as US Defense Secretary Donald Rumsfeld memorably put it during the Iraq War, by converting them into "knowables" in a simulated universe defined by a set of simultaneous equations, on the basis of which various projections could be made. Here Rumsfeld was offering a high-tech reenactment of the line of reasoning that had led James Ferrier to invent epistemology 150 years earlier. Thus, anything that counts as an "unknown unknown" is already knowable, which is to say, it exists—and, to recall Quine's quip, "to be is to be the value of a bound variable" (in, say, a set of simultaneous equations). In other words, the "unknown unknown" must satisfy certain parameters, which may be operationalized in various ways. Thus, while one might not know exact values, one would know "the margin of error." More generally, be it understood as happening in a "planned" or "blind" fashion, the economy might be modeled by algorithms that coordinate independent streams of input data into a concerted response. Indeed, on the basis of such systems-level thinking, one might try to achieve "planned" outcomes by "blind" means, or vice versa—which basically captures the political-economic space defined by market socialist and social democratic modes of provision (Fuller 2008). In principle, everything from the flow of money to the allocation of resources could be subject to this treatment.

Thus, the great Cold War interdisciplinary project, *cybernetics*, was born (Mirowski 2002, chap. 2). At the height of the Cold War, the MIT political scientist Karl Deutsch (1963) conceptualized the state as society's cybernetic brain, a metaphor that the UK management consultant Stafford Beer tried to render literal as the mastermind of Chile's ill-fated attempt to implement cybernetic socialism ("Project Cybersyn") via a mainframe computer that was located in a room destroyed during Augusto Pinochet's 1973 coup (Pickering 2010, chap. 6). In any case, many of devotees of this approach, not least Rumsfeld, made successful careers by applying the template. For better or worse, the exemplar of applied cybernetics (aka operations research) was Robert McNamara, whose early conversion to systems-level thinking at the Harvard Business School enabled him to run World War II bombing raids over Japan, turn around the fortunes of the Ford Motor Company, direct US military operations in Vietnam, and finally preside over the World Bank's push into development aid (Fuller 2000, p. 183).

The most radical and ultimately persuasive formulation of the military-industrial will to knowledge came from the man who led the Prussian troops to victory against France in 1871. According to Baron Helmuth von Moltke (1800–1891), a society should regard itself as always in a state of "permanent emergency," which amounts to thinking in terms of who or what might *next* threaten its very survival (Fuller 2000, pp. 105–109). This alerts the society to the need to reassert its existence in the face of ever changing circumstances. In short, peacetime is when you learn how to fight the next war. Thus, the image of society as organism and as system became fused in society's never-ending struggle to define the boundary between itself and the external environment. The significance of this fused image should not be underestimated. After all, "system" had been normally seen as a term in logic, the formal relations of parts to wholes, but now it was enmeshed with a substantive biological imperative whereby only those who advance (or grow) survive (or live). As we shall see, this epistemologically deep albeit paranoid vision came to fruition during the Cold War.

In Moltke's own day, the organicist conception of society played into the nineteenth-century conception of the state as guardian of a "nation," which is to say, a political entity grounded in the existence of a native population (to which nonnative citizens may or may not be added). It also played into such contemporaneous developments as Claude Bernard's "experimental" definition of death as an organism's failure to maintain a strong distinction between itself and its environment (i.e., death as blending) and Leon Walras's general equilibrium model of the economy as a self-sustaining mechanism. While Bernard's definition of death came to be seen as a special application of the principle of entropy in thermodynamics, Walras's model scaled up into a vision of society as a set of interlocking markets, which were kept in harmony by a regulatory state. Such a worldview was championed by Walras's younger contemporary, Vilfredo Pareto, who in turn was translated and promoted in the United States by the influential Harvard biochemist Lawrence Henderson (more about whom in the next section). Henderson's colleague, the physiologist Walter Cannon, coined the term "homeostasis" to capture this line of thought in its maximum generality. It was picked up by the sociologist Talcott Parsons, who aspired to an interdisciplinary science of "social relations," and especially the mathematician Norbert Wiener, in whose hands it became the cornerstone of cybernetics (Heims 1991, chap. 8).

For those following in Moltke's footsteps, "war" is simply the violent version of ongoing conflict that is normally played out in the marketplace. Just as rival producers ultimately aim for monopoly, nation-states should regard their rivals as promoting alternative hegemonic regimes to their own. In this respect, "peace" is simply the commercial sublimation of hostilities posed by the rival universalisms. But Moltke's idea truly came into its own in the Cold War, when first the laboratory and then the computer emerged as hybrid military-industrial platforms for playing out the interstate rivalry. Thus, starting with the Soviet launching of Sputnik in 1957 and including the rival US-USSR space missions and the various iterations of the "arms race," the mere display of technoscientific strength mattered more than its actual deployment, either in war or commerce. In the end, the United States won the Cold War simply by outspending the USSR, effectively bankrupting it. Thereafter many of the potential innovations that had been capitalized during the Cold War were quickly released into the marketplace, resulting in Silicon Valley and its various global emulators driving the post–Cold War economy. This in turn has opened up new national security concerns, captured nowadays in the various biotech hybrid discourses of "virus" (Mazzucato 2013).

Moltke had been inspired by Karl von Clausewitz's early nineteenth-century classic, *On War*, which is famous for defining war as "politics by other means." But he then took Clausewitz to the next level, arguably perfecting the "art of war." Here it is useful to think about war as proceeding along a dialectic. In the first moment, war is a natural extension of everyday conflict with no agreed rules or objectives—that is, until the parties see it as no longer in their interest to fight. Thus, Fabius, the third century BC Roman general credited with Hannibal's defeat in the Punic Wars, simply wore down his stronger opponents by forcing them to fight on his own turf, which then enabled his troops to win by deploying guerrilla tactics. In contrast, warfare in its second moment acquires clear strategic goals and mutually agreed rules of engagement of the sort that makes Clausewitz's definition ring true. This remains the default "modern" sense of war, in which the making and breaking of treaties between nations provide the official record of geopolitical affairs.

However, Moltke aspired to make war the limiting case of the human condition, which marks the third moment of the dialectic. In true Hegelian fashion, it reintroduces elements of the first Fabian moment. Thus, Clausewitz's well-defined opponent in a structured conflict is seen as also providing the environment through which one's own more existential objectives are realized. In this respect, the opponent is internalized as a means to one's own ends. Put bluntly: We need opponents to fully realize who we are and hence what is worth defending and promoting. The Cold War's self-consciously Manichaean struggle between capitalism and socialism epitomizes this equation of life and war, without any obvious end in sight. In concrete terms, it marked the advent of the military as the most proactionary agency of the state with regard to its approach to science and technology.

This expanded ambition to be a general science of strategic control appeared in a shift in military procurement policies from what was needed to fight the next version of World War II in the foreseeable future to what was needed to fight a genuinely novel "World War III" in the indefinite future. In this context, the UK political economist Mary Kaldor (1982) has written of the rise of a "baroque arsenal" that is preoccupied with rapid response and action at a distance as ends in themselves, regardless of specific short-term advantage. The relevance of this point to interdisciplinarity is that whenever the exemplar of this approach—the US Defense Department Advanced Research Projects Agency (DARPA)—is stereotyped as harboring "mad scientists," their "madness" typically relates to the scientists' refusal to accept the normal spatiotemporal parameters of discipline-based research (Belfiore 2009).

5.3 Academia and Business: A Case of Symbiosis or Mutually Assured Destruction?

To appreciate the issues at stake in this section, we need to take a brief detour through corporate history. Before the nineteenth century, the legal category "corporation" as an agency independent of the state with a distinct legal personality was reserved for civic, academic, and religious organizations. In this respect, the Royal Society was more of a "corporation" than the joint-stock companies that we now take to have been the original vehicles of capitalist expansion in seventeenth- and eighteenth-century Britain. Those companies ultimately depended on the favor of the monarch, who functioned as the principal shareholder, typically taking a personal interest in matters. However, the second half of the nineteenth century witnessed a wave of economic liberalization that allowed for the self-perpetuation of businesses on the corporate model, including limited liability to owners and rights to expansion, especially when seen to be in the public interest. Thus, "corporations" in this modern sense were permitted to minimize transaction costs by acquiring product-relevant supply chains and distribution channels. But just as importantly, corporations were allowed to throw open ownership to the marketplace, specifically the stock market, whereby the noncontrolling "shareholder" became the norm.

However, as Berle and Means (1932) famously showed, the net result of these shifts in corporate law was to drive a wedge between the ownership and control, and in the process deconstruct the concept of property. The market's democratization of owners as "shareholders" served to diminish corporate accountability, leaving it to a class of professional "managers" whose jobs depended on securing ever larger yields from shareholder investments—by whatever means. Relevant for our purposes is that the risky decisions taken by this new managerial class were typically informed and legitimized by interdisciplinary researchers employed by foundations that were financed by these very corporations, to which we return later in this section. Nevertheless, at the time, which coincided with the rise of communism and fascism, the point remained obscured. Instead, Berle and Means (1932) was read as having demonstrated the complementarity of mass democracy and authoritarianism, insofar as shareholders did not seem to care what managers did as long as dividends increased. And by the time the managers failed to do this, it was often too late to change course without significant losses, which historically culminated in the Great Depression. It was against this backdrop that US President Franklin Roosevelt extended the state's role as public interest regulator of the business world. Moreover, FDR himself turned to interdisciplinary researchers, including the corporate lawyer Adolf Berle, to constitute his "Brain Trust" who were entrusted with drafting legislation designed to ensure against any future corporate risk-taking.

The emergence of corporate foundations—Rockefeller, Carnegie, Ford, Sloan, and others—reflects a unique confluence of forces in early twentieth-century US political economy. At the intellectual level, there was the recognizably Baconian desire to unleash practical knowledge from its scholastic shackles, which extended to the opening up of research to areas of social life—most notably the workplace and the family—which academics had previously ignored. Why the neglect? The most obvious reason was these settings lacked the elaborated textual traces with which academics were most comfortable. Thus, until the early twentieth century, "history" generally meant the study of the speeches, memoirs, treatises, and treaties of major political players. Given that the quintessentially academic field of "cultural studies" routinely valorizes ordinary vis-à-vis elite lives nowadays, it is easy to forget that with a few notable exceptions (e.g., Friedrich Engels's early ethnographies of British working-class lives) most of the research into nonelites was originally commissioned by the state or industry. To be sure, the motivations for these commissions were often self-serving, but at least these powerful social actors recognized that their legitimacy depended on the well-being of the general population—an insight which did not naturally occur to academics.

Beyond this intellectual impetus, which also characterized the roughly contemporary rise of corporate foundations in Germany and elsewhere, there was the political need for American industrialists to adapt to the normative horizons of the emerging Progressive movement, whose default view of big business was one of tax-dodging monopolists, the ultimate rogues of public life. Nevertheless, the industrialists shared the Progressives' expansive sense of American nationalism, ultimately in aid of projecting the United States on the world stage. Thus, they positioned themselves to complement the emerging proactionary state championed by Theodore Roosevelt and Woodrow Wilson. Specifically, the foundations were key in resourcing foreign scholars whose work was disrupted by the two world wars, as well as providing the main financial support for research relating to the improvement of worker productivity and, at a still deeper level, health and education. The overall strategy worked, as the United States became a research leader of global standing, long before the establishment of a "National Science Foundation." However, the historian Charles Beard could already observe in 1936 that the *modus operandi* of foundations consisted in the manufacture and repair of "cultural lag," as they generated disruptive innovations in the home and at work which then provided the pretext for them to work with the state to move the masses to ever newer—and presumably higher—senses of "normal" (Kevles 1992, p. 205).

The response of university leaders to this agenda was mixed. Among those who fell out of love with the foundations' creative destruction of society was Robert Maynard Hutchins. As dean of Yale Law School in the 1920s, Hutchins invited the Rockefeller Foundation to establish an interdisciplinary social science institute to study and remedy liabilities in legal judgment, thereby seeding the modernizing movement known as "legal realism." But as president of the University of Chicago in the 1930s, Hutchins abruptly arrested the development of the social sciences (and opened the door to the more "humanistic" approaches associated with Leo Strauss and Friedrich Hayek) by refusing Rockefeller money, which he believed was responsible for the market volatility that resulted in the Great Depression. On this basis, Hutchins became a convert to "perennial philosophy" and natural law theory in the Neo-Aristotelian mold (Ross 1991, pp. 400–403). In striking contrast, upon becoming Harvard's president in 1933, the chemist James Bryant Conant made it much easier for the foundations to access Harvard faculty and resources. As the first scientist to run an Ivy League institution, Conant was more comfortable with the socially disruptive character of scientific innovation, which academics were ideally positioned to study, manage, and capitalize on. Here he had been inspired and promoted by the Harvard biochemist Lawrence Henderson, mentioned in the previous section, who worked with the industrial sociologist Elton Mayo on the famous Rockefeller-funded "Hawthorne" studies on the environmental factors informing worker productivity (cf. Fuller 2000, chaps. 3–4; Isaac 2011, chap. 2).

The largely symbiotic relationship between corporate foundations and big government in the United States in the first half of the twentieth century amounted to an implicit division of labor over research funding. At first, the state treated science and technology policy as an extension of domestic development policy, largely on the model of the land-grant universities established in rural regions in the nineteenth century. The focus was on applied research. Indeed, when the prospect of a permanent "National Science Foundation" was debated in the years immediately following World War II, MIT Vice-President Vannevar

Bush had to coin the phrase "basic research" to capture another basis—the one that ended up prevailing—on which the state might wish to fund science (Fuller 2000, p. 151). In contrast, the foundations always knew about basic research, which they practiced in the spirit of Stokes (1997), discussed at the start of this chapter. From their standpoint, a field like "molecular biology" (a Rockefeller coinage) was about improving the capital stock from which better products might flow in the future. But here "capital stock" refers to not only better crops and livestock but also better humans. Thus, while a discipline-driven view of knowledge might view "eugenics" as the (mis)application of genetic science, the foundations saw eugenics and other broadly "social" sciences in "basic research" terms that aimed to extend human potential indefinitely (Kay 1993).

This conception of basic research meant that the foundations had to think creatively about how to navigate their investments through the twentieth century's political-economic volatility, much of it arguably of its own creation. For example, in the wake of the Great Depression, as director of natural science research, Warren Weaver—now remembered for the Shannon-Weaver entropy-based communication theory—steered the Rockefeller Foundation away from providing seed money and toward funding extant discipline-based research that could use the money to develop synergies in interdisciplinary projects (Kohler 1994, Part III). This was the spirit in which Weaver first identified "molecular biology" as a field of interest for the foundation in the 1930s, which incentivized physicists and chemists to migrate to biology, eventuating 20 years later in the discovery of DNA's double helix structure. Interestingly, the US National Science Foundation in the first decade of the twenty-first century adopted a similar strategy to promote a broadly "transhumanist" agenda to bring together nano-, bio-, info-, and cognosciences in common projects aimed at "enhancing human performance" (Fuller 2011, chap. 3). But generally speaking, once the NSF was created in 1950, the foundations took on riskier interdisciplinary research assignments—such as radiation-based medicine and mechanical models of the brain (aka neuroscience)—which were unlikely to survive the discipline-based peer review processes instituted at the NSF (Kevles 1992, pp. 209, 221).

Finally, the long-term effect of the foundations on the corporate form of business itself is worth pondering. The lifework of Alfred Chandler, arguably America's premier business historian, can be understood as having been about the disintegration of the modern corporation through a pincer attack from natural and social scientists in the twentieth century. Chandler himself did not put matters this way, but it captures the dynamic described in Chandler (1962), which recounts how the corporation moved from being organized in *functional* to *divisional* terms, the former characterized by mass production and the latter by market specialization: "Fordism" and "post-Fordism," as cultural sociologists put it. The research legitimizing the former was natural-science-led, the latter social-science-led. Frederick Winslow Taylor and Abraham Maslow are the respective patron saints of these approaches. On the one hand, you might strive to produce something so inexpensive yet useful that you conquer the market through mass acceptance. On the other hand, you might strive to customize what you already produce to distinct markets, even though that may mean investing more in learning about your customer base than in physically changing your product (Stinchcombe 1990). Yet, this bipolar strategy has arguably led to the business world's version of "imperial overreach," whereby the corporation's identity (or "brand") becomes compromised by trying to be all things to all people.

5.4 Conclusion: The Cautionary Tale of Fritz Haber and Larger Lessons for Interdisciplinarity

A theme that has run throughout our account of the military-industrial route to interdisciplinarity is the promethean potential of "undiscovered public knowledge," those products of epistemic associations that stray beyond the path-dependencies of established paradigms. Etzkowitz (2002) credits Vannevar Bush, when working at the MIT Electrical Engineering Department in the 1920s, with recommending that academics regularly consult with business to get new ideas and even form what are now called "start-up" firms. A Bush student, Frederick Terman, took this inspiration to the US West Coast, where as Stanford provost in the 1950s, flush with federal funds, he built the academic hub for today's Silicon Valley. While a question mark remains over the ultimate economic efficacy of the information technology revolution unleashed from Silicon Valley since the end of the Cold War, so far it has been generally seen as a "good thing." But as some of the more hyperbolic claims relating to "artificial intelligence" come closer to realization, storm clouds may be brewing—and here history may provide an instructive precedent.

A key transition in the evolution of interdisciplinarity came with the adoption of what is nowadays called the "triple helix" model of state-industry-university relations, the signature institutional formation of "Mode 2" or "postacademic" knowledge production (Gibbons et al. 1994). When the origins of this model are traced to the post–Cold War era, marking the end of state-protected academic enterprises and the onset of a more "postmodern" and "neoliberal" sensibility, it is easy to see the transition as hostile to classic academic ideals of research autonomy. However, if one goes back to the model's true origins in Germany's Kaiser Wilhelm (now Max Planck) Institutes in the early twentieth century, the picture looks rather different. What had been already recognized for a century as academia's centrality to the long-term national interest was extended from crafting future leaders in the classroom to crafting innovative products in the laboratory, as academics were politically permitted a freer hand in dealing with industry (Fuller 2000, pp. 107–108).

The exemplar of the massive power—for both good and ill—unleashed by the original triple-helix model is Fritz Haber (1868–1934), who for more than two decades worked at the Kaiser Wilhelm Institute for Physical Chemistry. Haber was awarded the 1918 Nobel Prize in Chemistry for discovering the ammonia synthesis process, which is responsible for both the artificial fertilizers that have provided sustenance for billions of people and the chemical weapons that have killed millions of the same people in warfare over the past hundred years. (In the latter case, I mean the explosives he developed from nitric acid, but he also more famously worked on chlorine- and cyanide-based "poison gas" weapons.) What is now known as the "Haber-Bosch process" involves harnessing nitrogen from the air—78% of the Earth's atmosphere is nitrogen—instead of having to rely on material deposits.

Despite the idiosyncratically interdisciplinary character of Haber's work, it had real-world effects, given his easy access to heavy industry's capacities to scale up the production and distribution of innovations. While industry's role in Haber's success is generally noted, starting with his father having been a dye manufacturer, the interdisciplinary character of his thinking tends to be overlooked. Nevertheless, surprisingly for a "physical chemist," Haber's tripartite doctoral examination reveals someone excellent in philosophy, adequate in chemistry, and poor in physics (Charles 2005, pp. 19–20). Two marks of Haber's interdisciplinarity are relatively obvious. The first is the geopolitical significance of maintaining bread as a food staple in the West, amid growing rice production in the rapidly modernizing East. Haber quickly enabled Germany to become agriculturally self-sufficient, no longer needing to import nitrogen-rich guano from Latin America. This striking success launched the ongoing political discourses over "food security" and, more generally, "energy self-sufficiency" (Smil 2001). The second interdisciplinary feature is the conversion of insecticides (largely to protect the new artificially grown crops) to munitions for use against humans, thereby shifting the ontological status of the enemy to that of an animal, which introduced a mode of strategic thinking into warfare that the Nazis would make explicit, not least via "Zyklon B," the insecticide developed by Haber that was used in the gas chambers of the Holocaust.

However, a third mark of interdisciplinarity was perhaps the deepest and appealed to the Kaiser Wilhelm trustees. It was the idea that ammonia synthesis allowed for the creation of "bread from the air," in the original marketing phrase for artificial fertilizers. This was basically a secularization of the biblical "manna from Heaven," a reference to God's provision of purpose-made sustenance to the Israelites in their 40 years of desert wandering from the time of escaping their Egyptian captors to the arrival at the Promised Land (Exodus 16; John 6). The Kaiser Wilhelm Institute's main ideological defender was the German higher education minister, the liberal Protestant theologian Adolf von Harnack, in whose house Haber conducted some of his most influential seminars during World War I, which Harnack notoriously announced would be won by Germany because of its unique confluence of divine and scientific power (Charles 2005, p. 118).

If greatness were measured simply in terms of control over the number of lives *both* made and lost across the planet, Haber would have to be considered the single greatest person of the twentieth century, if not all time. Indeed, the nonscientific work of one of Haber's most promising understudies, Michael Polanyi, may be understood as having been written in violent reaction to this prospect, which he diagnosed in terms of Haber's instrumentalist philosophy of science (Fuller 2000, pp. 139–140). Moreover, Haber-like claims used to be made about the original subatomic physicists, yet interestingly nuclear fission—let alone fusion—has yet to match the level of both benefit and harm wrought by the ammonia synthesis process. Just as we have not had to endure a thermonuclear war, neither have nuclear power plants provided cheap and safe energy to most people. Of course, both could change in the future, perhaps with the help of a Haber-like interdisciplinary genius equipped with artificial intelligence.

Most theoretical discussions of interdisciplinarity treat it as something that is achieved within the academy, with more or less resistance from fellow academics and with more or less pressure from outside the academy. The military-industrial route to interdisciplinarity challenges this starting assumption by denying much of the sovereignty that academics have over the knowledge they produce. "Sovereignty" here covers not only the uses to which academic knowledge is put but also the very means by which the knowledge is produced. The military and industry have been emboldened in this way for several reasons that have surfaced in this chapter. The main one has been that academic knowledge production tends to be strongly path-dependent (aka paradigm-driven) and underused to the point of being ignored even by other academics. Behind this concern is a faith that the key to human salvation is the full realization of our (god-like) cognitive capacities. Thus, we hold ourselves back by not taking full advantage of all that we know—and can know. Lest one find this faith naïve or fanciful, it is worth recalling that those who have promoted the military-industrial will to knowledge have been themselves academically trained. They have experienced first-hand the empowering character of academic knowledge, which they may now find their teachers short-selling. In short, what has been provided here is an account of interdisciplinarity from the standpoint of the successful alumni.

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PART II

INTER- AND TRANSDISCIPLINARITY AND THE DISCIPLINES

CHAPTER 6

PHYSICAL SCIENCES

ROBERT P. CREASE

INTERDISCIPLINARY research and collaboration is surely as old as science itself. In a three-part article in *Scientometrics*, Beaver and Rosen (1978, 1979) examined the entire history of scientific collaborations, including interdisciplinary ones, through a coauthorship study.

Interdisciplinary research is seductively easy to theorize about, and can give rise to high-minded glorifications of "boundary-crossing," "transgression," and the production of "new objects." Yet interdisciplinarity is more treacherous than it looks. The advantage of the case of the physical sciences is that interdisciplinarity can be looked at concretely in ways that can help to weed out much posturing and ideology.

6.1 History

The beginning of the nineteenth century witnessed a disciplining of modern science, when it came to be conceived as consisting of relatively discrete and specific bodies of knowledge or "logies." However, this development was also accompanied by the recognition that the knowledge embodied in each discipline bore on others, and that understanding any particular slice of human life involved a spectrum of fields. These two poles are illustrated by Humphry Davy's famous introductory lecture on chemistry at the Royal Institution in 1802, in which he extolled the value of chemical knowledge for a multitude of sciences and throughout human life and experience, and by Michael Faraday's equally famous discourse at the same institution about half a century later, in which he showed that the complete understanding of a single, simple candle involves many different fundamental laws of nature, from capillary action to gravitation.

When Auguste Comte propounded his scheme of classification of the sciences, he argued that while "the division of intellectual labor" was necessary and the disciplines would have to be separately cultivated, he also stressed that the sciences all belonged to a "greater whole" and that any division was "at bottom artificial." He warned against "too great a specialization of individual researches" as "pernicious," because the end of science was to understand the world around us, which is inherently complex and cannot be addressed by any single discipline (Comte 1988, pp. 16–17).

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6.1.1 Emergence of Interdisciplines

Early interdisciplinary research projects often took the form either of researchers applying techniques (whether theoretical or experimental) cultivated in one field to another, or of researchers in one field working at the frontier of another. Warren Hagstrom (1964, 1965) compared early forms of collaborative research in science to medieval forms of economic organization. Professor–student relationships, for instance, resembled master–apprentice relations, while "free collaborations" resembled medieval partnerships. The latter are initiated informally, and Hagstrom likened their initiation process to courtships in which suggestions of interactions are cautiously initiated and explored, often accompanied by fear of rejection (Hagstrom 1965, p. 114). But Hagstrom wrote that just as modern corporations have come to dominate both apprenticeships and free partnerships, so a more complex form of collaboration was arising that would soon dominate scientific research. The roots of this more complex and corporate form of collaboration, he wrote, were threefold: (1) centralization of authority imposed from above by institutions or funding agencies and by large and expensive facilities, access to which was necessarily restricted; (2) a necessary division of labor among various kinds of technicians and experts; and (3) interdisciplinarity, which can be contrasted with *multidisciplinarity*, or mere division of labor among disciplines.

Such more complex collaborations began to emerge early in the twentieth century. As Davy had prophesied, chemistry was often a principal ingredient of interdisciplinary collaborations in fields such as biophysics, physical chemistry, and chemical engineering. Other interdisciplinary fields to emerge in the early twentieth century included radiation science, which combined elements of physics, chemistry, engineering, biology, and medicine, and cybernetics, which brought together pieces of architecture, control systems, electronics, game theory, logic, mechanical engineering, neuroscience, psychology, and philosophy. Sometimes interdisciplinary projects were a function of the goal of a specific set of researchers, such as the famous astrophysics paper, "Synthesis of the Elements in Stars," that sought to explain the formation of heavy elements in stellar interiors (Burbidge et al. 1957). At other times, interdisciplinary research was deliberately cultivated by individuals at funding agencies, such as Warren Weaver of the Natural Sciences Division of the Rockefeller Foundation (Kohler 1991). Interdisciplinary research often forced laboratories such as the Radiation Laboratory at the University of California at Berkeley, and projects such as astronomical and space programs, to devise efficient ways to handle it (Everitt 1992; Seidel 1992).

The discovery of the molecular structure of DNA in 1953 was an important landmark, and generated a special set of problems for researchers. One was a certain amount of *disciplinary anxiety* that biology was about to be colonized by other fields, leading to A. V. Hill's rejoinder that "Physics and chemistry will dominate biology only by becoming biology" (cited in Pantin 1968, p. 24). It also inspired some rudimentary reflection about interdisciplinary research; Carl Pantin, for instance, was moved to propose what he called a "real" distinction between *restricted* and *unrestricted* sciences, or those (like physics, he thought) that do not require investigators "to traverse all other sciences," and those (like biology) where the "investigator must be prepared to follow their problems into any other science whatsoever" (Pantin 1968, p. 24).

In the 1960s, when Hagstrom wrote, applied research, especially industrial research such as DuPont's, already tended to be interdisciplinary. "Better living through chemistry" was then a popular adaptation of an advertising slogan adopted by the DuPont chemical company in 1935 and used for almost half a century to market its research and development projects across many fields (for the past decade the company has used the more generic slogan "The miracles of science"). But Hagstrom remarked that interdisciplinarity was much less common in basic research. When it did exist, he wrote, it experienced strains of the sort that befall "inherently heterogenous" emerging disciplines (Hagstrom 1965, p. 215), manifested for instance by behaviors such as obsessive celebration of a field's founders. Interdisciplinary work indeed can create not just disciplinary anxiety but also an intense kind of personal anxiety. When boundaries that have been taken for granted come to appear movable, it not only opens the question "What is the discipline?" but concomitantly the more personal questions "What am I doing?" and "Who am I?"

Today, the situation faced by Hagstrom has changed, and interdisciplinarity is common throughout basic research in fields such as addiction research, bioengineering, biological physics, biophysics, climate change, nanotechnology, and polymers. In 2000, the Nobel Prize for Chemistry was awarded to three scientists—two chemists and a physicist—for "the discovery and development of conducting polymers." In his acceptance speech, Alan J. Heeger, the physicist of the trio, remarked that simply by attempting "to understand nature with sufficient depth," he had "evolved . . . into an interdisciplinary scientist," for the field was "inherently interdisciplinary" (Heeger 2000).

6.1.2 Interdisciplinary Instruments, Facilities, and Techniques

Interdisciplinary research has affected instruments, facilities, and techniques involved in experimental research by fostering their deliberate planning and construction. Many new devices and techniques, particularly imaging technologies, apply to more than one field. X-rays are a classic example; within 3 weeks of their discovery in January 1896, physicians had used them to help reset a child's broken arm. But the scale and expense of modern instruments makes it necessary to maximize their constituency and design and promote facilities from the outset as dedicated for interdisciplinary use. Synchrotron light sources and supercomputers are classic examples.

Yet the impact of interdisciplinarity on research takes still more complex forms. All experimentation is a species of *performance*, for it involves bringing together well-understood pieces of equipment and material in staging an event or series of events that seek to make some phenomenon appear, and let it be examined, in a way that would not otherwise be possible (Crease 1993, 2003). Staging performances requires *production*, or an advance set of behaviors and decisions necessary to assemble elements created for other purposes. The production of research equipment thus sometimes requires a kind of improvised engineering that John Law has called *heterogeneous engineering* (Law 1987). But the equipment of modern interdisciplinary research is of such a scale that not just pieces of knowledge and apparatus but also entire fields of knowledge are sometimes transformed and whole instruments reconstructed for new purposes, resulting in what Catherine Westfall has called *recombinant science*.

Recombinant science does not occur as a natural outgrowth of previous research, but involves researchers combining "insights and expertise from various subfields in new ways to create a brand new outlook" (Westfall 2003). In small-scale interdisciplinary collaborations, the end is generally a natural outgrowth of traditional interests, and the means require recruiting and coordinating researchers from different fields. Recombinant science, however, involves an untidier story, in which the ends as well as the means have arisen as the result of contingencies and convergences that require researchers to adapt their intentions and methods, sometimes awkwardly.

6.1.3 The Example of the Relativistic Heavy Ion Collider

A case study in recombinant science is the construction of the relativistic heavy ion collider (RHIC), a $486-million nuclear physics facility at Brookhaven National Laboratory. It sprang from a high-energy physics proton collider named ISABELLE, on which construction began in 1978 (Crease 2005a, 2005b). But various problems caused the US physics community to lose enthusiasm for the ISABELLE project (briefly renamed the colliding beam accelerator, or CBA), and it was terminated in 1983. In a remarkable turn of events, the facility was converted into a facility of a new sort to explore a new field, relativistic heavy ion physics. To justify this transition, scientific subfields were invoked that did not exist at the time of ISABELLE's birth, and the transition was made possible by certain key hardware components that also did not exist when ISABELLE was conceived. The new field of heavy ion physics effectively blended, initially with difficulty, nuclear and high-energy physics (Crease 2008).

6.1.4 The Age of Interdisciplinarity

Why has interdisciplinarity become so routine in the physical sciences? Several theories have been advanced.

One, advanced by Hagstrom, is corporate; the scale of scientific projects and facilities now requires corporate-style organization and management in which different disciplinary components are coordinated (see Hall et al., this volume). Indeed, such organizations have now been around long enough that patterns have developed. In their study of multi-institutional collaborations, for instance, Shrum et al. (2007) identified five different patterns of collaboration formation and four organizational types of collaboration, and note several bureaucratic features that have evolved to stabilize such interdisciplinary research.

Another theory, advanced by the historian of science Paul Forman (2007), is epochal; the rise of interdisciplinarity is tied to the shift from modernity to postmodernity. The assumptions of modernity—especially the priority of theory over practice, of basic over applied research, and of disinterested over interested knowledge—produced the traditional disciplinary borders, and served to reinforce them. These disciplinary structures have all but collapsed as an inevitable consequence of the reversal of the priority of science and technology characteristic of postmodernity, with its "pragmatic-utilitarian subordination of means to ends, and of the concomitants of that predominant cultural presupposition, notably, disbelief in disinterestedness and condescension toward conceptual structures" (Forman 2007, p. 2).

A third theory is historical; that two seminal events—the development of quantum mechanics and the massive expansion of computational power—made interdisciplinarity all but inevitable. Quantum mechanics forced the reworking of the foundations of physics, chemistry, biology, materials science, electronics, thermodynamics, and other fields. It provided scientists with the confidence to claim that enough was known about the structure of matter so that, even if only in principle, large-scale substances and many real-world behaviors could be traced back to, if not entirely explained by, small-scale structures and forces. And the sciences of these large-scale substances and real-world behaviors—from proteins to superconductors—were not abstract domains like particle physics or cosmology but inherently interdisciplinary "real-world" systems.

The expansion of computational power, meanwhile, also transformed nearly all the physical sciences not only through codes and calculations—which have often made it possible to trace back the behaviors of large-scale substances to small-scale structures and forces—but also through data analysis and fitting, search techniques, simulations, visualization methods, and other tools. This has led to what Wilson (1984) called the "computerization of science." It also led to the interdisciplinary field (applied mathematics, computer science, and science and engineering) of computational science and engineering (CSE), which itself is a field that participates in other interdisciplinary fields (on its impact just on physics see Landau et al. 2008). Computation has also profoundly affected disciplines outside of the natural sciences, including art. Recognition of the relevance of mechanics and optics to painting dates back at least to Leonardo da Vinci's *Treatise on Painting* and Hermann von Helmholtz's lectures *On the Relation of Optics to Painting*. Yet the recent expansion of computational power (plus technological developments such as the development of selective laser sintering devices) has transformed the practice of artists in striking ways, such as in the recent emergence of the field of "mathematical sculpture" (Grossman & Hart 2008; Zalaya & Barrallo 2008), which includes representations of four-dimensional objects—the creation of a "new object" if there ever was one (Figure 6.1).

Yet a fourth theory offers a Comtean-style teleological explanation involving the purpose of science itself. The point of science is to allow the prediction and control of nature, and if we have divided science into disciplines it is only so that we can better cultivate them to the point where we can do this. We have had a learning curve while the disciplines were being

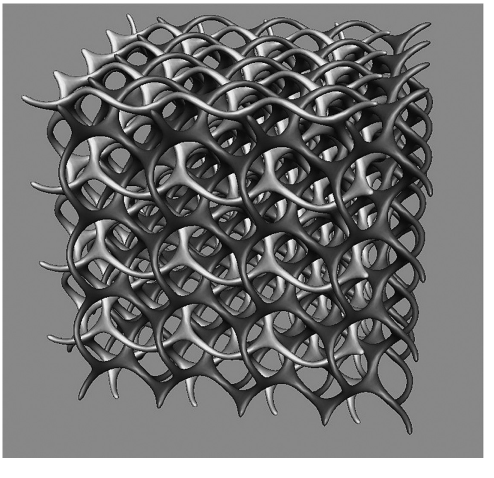

FIGURE 6.1 A "mathematical sculpture."

Courtesy George W. Hart.

cultivated, but at last we can bring them together again in interdisciplinary research. Any obstacles to so doing are the result of what Comte called the "pernicious effects of an exaggerated specialism."

For whatever reason—corporate, epochal, historical, or teleological—interdisciplinarity is here to stay. Many people have referred to the "frontier of complexity," whose manifestations include biotechnology and nanotechnology, and which ensures that interdisciplinary research will dominate the natural sciences in the twenty-first century, a period sometimes referred to as the "Age of Interdisciplinarity" (Marburger 2008).

6.1.5 The New Big Science

In the past few years, historians of contemporary science have detected a new phase in interdisciplinary research at large facilities which they have baptized "The New Big Science." The Old Big Science, typified by instruments such as particle accelerators and fields such as high-energy physics, involved ever-larger facilities, instruments, and collaborations. The science at these facilities was primarily basic; if it found applied use or industrial applications these were parasitic on the main research function. In the New Big Science, large-scale materials science facilities have become the marquee projects at the major basic research laboratories, accompanied by important changes in the character and culture of the interdisciplinary research ecosystems at these laboratories. The instruments and collaborations have not grown bigger and bigger; instead, the research ecosystem has grown more complicated. It involves more and more fields, a wider variety of instruments, more connections between research programs, and a faster turnover of programs. The New Big Science is typified by nanotechnology, whose story involves neither ever-bigger research tools nor a linear tale of breakthroughs followed by practical applications. Rather, the story of nanotechnology involves a stable scale of instruments, and intertwined utopian visions, industrial benefits, interdisciplinarity, and national goals from the beginning (McCray 2005).

6.2 Practical Issues

Promoting the growth of interdisciplinary research is surely a fine goal. But as the Spanish proverb says, it is one thing to speak about bulls and another to be in the bullring. Fortunately, scientists and science administrators have had decades of experience trying to meet the concrete and practical challenges of interdisciplinary research. One speaker at a 2006 American Association for the Advancement of Science (AAAS) workshop on quality assessment in interdisciplinary research prefaced his remarks by recalling US President Grover Cleveland's blunt remark, in vetoing a tariff bill, that "This is a condition we face, not a theory." Interdisciplinarity is indeed a condition with pressing challenges that often do not respond nicely to theory. Its challenges vary throughout the phases of a project such as the construction of a big facility—from construction to operation to data analysis—and are also different for theoretical research. Practical challenges of the condition of interdisciplinary research in the physical sciences include coordination, quality assessment, communication, and culture.

6.2.1 Coordination

One set of practical issues arises in laying out the conditions in which the various disciplines can work comfortably. Again, the example of the RHIC is illustrative. Nuclear and high-energy physicists would not only have to learn and adapt techniques from each other but also learn to work comfortably together—yet their existing practices were quite different, using different kinds of instruments and different sized teams, with nuclear physicists used to working with a handful of collaborators, and high-energy physicists used to collaborations of dozens or even hundreds. At a key meeting at the beginning of the project, Arthur Schwartzchild, the chairman of Brookhaven's physics department, outlined a plan to address the problem by initiating an interim program of heavy ion physics at existing facilities at the lab that would run while RHIC was under construction. This, Schwarzschild said, would address the looming "manpower and sociology issues" by "building a constituency for collider experiments, effecting collaborative efforts between nuclear and particle physicists, and providing an appropriate arena and stimulus for detector development necessary for collider experiments." In an interesting unwitting echo of Hagstrom's relationship metaphor, Schwarzschild concluded by saying, "The new physics calls for a marriage between nuclear and high energy experimenters, and this conference looks like an engagement party to me" (Ludlam & Wegner 1984, p. 377c).

6.2.2 Quality Assessment

But such relationships still need to be monitored for their long-term health. In 2008, Boix Mansilla and Gardner wrote, "a re-emerging awareness of interdisciplinarity as a pervasive form of knowledge production is accompanied by an increasing unease about what is often viewed as 'the dubious quality' of interdisciplinary work." One factor is that the traditional method of quality assurance—peer review—can prove difficult in practice in the absence of true "peers" (see Holbrook, this volume). A step in alleviating this concern, the authors continued, is to develop suitable processes, criteria, and contexts for assessing interdisciplinary work, including ways of selecting appropriate reviewers and of effectively managing their collective expertise in review sessions. One must find, as Martin Blume, the former editor-in-chief of the American Physical Society put it at the AAAS quality assessment meeting mentioned above, "referees who have open minds and a deep knowledge of the fields." Among the problems is "a tendency of physicists to believe that another area of science is not significant until it can be understood in terms of the techniques of physicists, and for, say, economists to believe that physicists have nothing to teach them" (Blume 2006). Another problem involves metrics for evaluation, such as citation counts or publication in "high impact factor" journals, for different fields may be of different sizes and differ, too, in the shelf life of influential articles. Groups such as the Council of Environmental Deans and Directors of the National Council for Science and the Environment provide online resources for interdisciplinary hiring, tenure, and promotion (CEDD 2008).

Other special measures that may be required to ensure the quality of fields include making sure that the appropriate spectrum of journals turns up in citation indexes; that once articles in journals such as *Physical Review E* and *Physical Review Letters* become relevant to medical research, for instance, these journals are listed in Medline. Special awards for interdisciplinary research may be necessary to ensure that noteworthy research that may otherwise slip through the cracks is appropriately recognized. The New York Academy of Sciences, for instance, sponsors an annual award, the Blavatnik Award for Interdisciplinary Research. And interdisciplinary research poses special problems for librarians and information scientists: "It is imperative for information scientists to understand the characteristics of interdisciplinary research and the researchers' information need(s) to better serve the scientific community" (Tanaka 2008, p. 41).

6.2.3 Communication

Thomas Kuhn famously argued that disciplines are defined by paradigms. If so, then any crossing of disciplines can only be either undisciplined, or a trade or exchange of something between disciplines: multidisciplinary rather than interdisciplinary. How is genuine cross-communication possible? Peter Galison provided a twofold answer involving the claim that paradigms are not that monolithic plus the idea of a trading zone, or special kind of place where different cultures meet and interact. What takes place in such a zone, he claims, is not "translation," with its implication of one-step transpositions of meaning from one holistic context into another. Rather, local languages emerge—interlanguages, "pidgins and creoles"—that "grow and sometimes die in the interstices between subcultures." In this way, "trading partners can hammer out a *local* coordination, despite vast *global* differences" (Galison 1997, p. 783; Collins et al. 2007).

6.2.4 Culture

But interdisciplinary research involves more than language. Seligman et al. (2008) point out that, in genuine communal interaction, it is often more important to examine what people do rather than what they say or mean. One must beware of overtextualizing the world, of overemphasizing the efficacy of language and belief in human action. Despite the detached, third-person style of research papers, what matters is not whether the result is epistemically justified, but whether the goal has been reached. The language of science is subservient to the practical requirement of achieving its goal. This signals the importance of another set of subjects critical to interdisciplinary research—its "immaterial culture," so to speak—including trust and expertise, to be mentioned below.

Cooperation, for instance, may require overcoming cultural differences, not just learning a new language. An example is provided by what happens to the Stony Brook University computer engineer Steven Skiena each time he teaches his graduate course in computational biology. The two largest groups who take his class are biologists and computer engineers, and these have diametrically opposed backgrounds, experience, interests, and educational attitudes. From the beginning, it was difficult. "The biology students took for granted the existence of a strict hierarchical pecking order that leads from professor to postdocs to grad students to lab assistants to undergraduates, and assumed that they must start at the bottom and work up. The computer students, by contrast, saw no such hierarchy, described themselves simply as working in the 'Skiena lab,' and treated everyone as peers, including

Skiena himself. The biology students tended to feel violated if asked to program a computer, and computer engineers tended to feel likewise if asked to learn something about proteins" (Crease 2006, p. 226).

It is two disciplines, one might say, divided by a common subject. Skiena must get the class at least to mingle intellectually. He begins by mirroring back these cultural differences in a slide (Figure 6.2). The PhD students in this class tend to retain their disciplinary affiliations after graduation—the computer science students tend to get jobs in computer science

Computer Scientists vs. Biologists

There are many different types of life scientists (biologists, ecologists, medical doctors, etc.), just as there are many different types of computational scientists (algorists, software engineers, statisticians, etc.).

There are many fundamental cultural differences between computational/life scientists:

- *Nothing* is ever completely true or false in biology, where *everything* is either true or false in computer science/mathematics.
- Biologists strive to understand the very complicated, very messy natural world: computer scientists seek to build their own clean and organized virtual worlds.
- Biologists are *data* driven; while computer scientists are *algorithm* driven.

  One consequence is CS WWW pages have fancier graphics while Biology WWW pages have more content.

- Biologists are much more obsessed with being the first to discover something; computer scientists invent more than discover.
- Research biologists have to know more than computer scientists; computer scientists know how to do more.
- Biologists are comfortable with the idea that all data has errors; computer scientists are not.
- Biologists live in stronger hierarchies than computer scientists; PI → postdocs → graduate students → lab assistants.

  Genetics students seeking to work with me ask to join the "Skiena lab".

- The Platonic ideal of a biologist runs a big laboratory with many people. The Platonic ideal of a computer scientist is a hacker in garage.

  Biologists can get/spend infinitely more research money than computational scientists.

- Biotechnology/drug companies are largely science driven, while the computer industry is more engineering/marketing driven.
- Biologists seek to publish in prestigious journals like *Science* and *Nature*. Computer scientists seek to publish in prestigious refereed conference proceedings.

  One consequence is life science journals get refereed faster than computational science journals.

- Computer scientists can get interesting, high-paid jobs after a B.S. Biologists typically need to complete one or more postdocs.

FIGURE 6.2 Introductory slide from Steven Skiena's Computational Biology class. Courtesy Steven Skiena.

departments, the biologists in life science departments—which no doubt is a function of teaching, tenure, and funding factors. However, they do tend to wind up publishing or copublishing much more in the other discipline—thus engaging more in interdisciplinary work—than their disciplinary peers.

6.3 Theoretical Issues

What is distinctive about interdisciplinary research in the sciences is that they do it more and theorize about it less. Scientists are accustomed to redrawing their disciplines, and live and work with their boundaries under reconstruction. The practical, goal-oriented focus of the researchers allows them to bypass the need for reflection and intersubjective inquiry. Moreover, theorizing about scientific practice is the task of other kinds of scholars.

6.3.1 Disciplines and Interdisciplines

One way to understand interdisciplinarity is through understanding disciplinarity. What constitutes a discipline: objects? methods? concepts? culture? Are the RHIC researchers actually being interdisciplinary, or merely retreading within what is essentially the same large discipline of physical science? And is interdisciplinarity in the physical sciences different from what happens in social sciences and the humanities? Are there different kinds of boundaries? Examining such questions using case studies from the physical sciences can help clarify what we mean by a discipline.

A *realist* conception of disciplines would picture science as seeking to describe territories of knowledge or of objects that are out there independently of how we come to know them—where nature is divided at its joints. If we make changes in what our sciences encompass we are correcting these boundaries to be more in accord with what is out there, rather than transforming the sciences or acting interdisciplinarily. In this view, the skeptics are right, and interdisciplinary research is arbitrary, hybrid, a disciplinary mule—sterile, not creative, and dependent for its continued existence on further seminations. But it has proven difficult to differentiate disciplines by their global object, or what the scholastics called their material object. Each discipline comes at its objects in a different way, so the disciplinary objects differ—what the discipline sees in the global object is based on the discipline's own ways of investigating. Indeed, there seem to be only nominal and historic differences between physics, chemistry, biology, and so forth, in terms of their global and formal objects.

For this and other reasons, following the appearance of Kuhn's *Structure of Scientific Revolutions*, we have seen the emergence of what might be called a *postmodern* conception of interdisciplinarity, exemplified by Forman. In this view, the boundaries of disciplines are essentially arbitrary, as a function of how these sciences emerged and the social forces exerted on them, susceptible to change as these forces change. *We* created nature's joints. Indeed, if the disciplines make any attempt to resist the transformation of their boundaries they become suspect as ideologies, subject to a hermeneutics of suspicion of their justifications of their interests, claims, and narratives. The postmodern conception of disciplinarity valorizes, even celebrates, interdisciplinary work and its heterogeneity.

A third possibility is a *hermeneutical* conception of disciplines, in which the sciences are about the world as it presents itself to us and with which we are creatively engaged through our laboratory experiences. The world does not present itself to us as undifferentiated, but as being landscaped, certain of its regions being nearer or farther from others. We inherit, adapt, and transform this landscape—you first have to recognize and accept boundaries in order to reorganize or transgress them—both the areas constituting it and how these are related. When X-ray instruments first appeared, they could be used in different fields without significantly affecting the boundaries. By the time that synchrotron light sources appeared, however, the engagement with nature to which X-ray technology belonged—the scales and energies involved—had been sharply altered, and human beings and nature were positioned very differently in a changed landscape.

6.3.2 Trading Zones

Another path to understanding interdisciplinarity involves looking at what happens in interdisciplinary projects. Collins et al. (2007) sought to develop a more general form of Galison's notion of trading zones, or places where different cultures interact. Noting that in the absence of communications problems there is only trade, they defined trading zones as "locations in which communities with a deep problem of communication manage to communicate." How, then, can such a "deep problem of communication" be overcome? In several possible ways, say Collins et al., depending on the kind of trading zone it is. They propose a fourfold division of such zones by mapping interdisciplinary collaborations onto a graph with two axes. One involves whether the collaboration is cooperative or coerced, the other whether the end product is a heterogeneous or homogeneous culture (Figure 6.3). In this way, the creation of new scientific disciplines like astrophysics, biophysics, or relativistic heavy ion research is only one of several possibilities for interdisciplinary collaborations. But the diagram is based on the assumption of a neat distinction between cooperation and coercion—which reminds philosophers of the old Aristotelian distinction between natural and enforced motions, and inspires wonder about the grounding of this distinction. How is this distinction reflected in scientific practice? Is the interaction between nuclear and high-energy physicists at the RHIC

<table>
<tr><td></td><td>Homogeneous</td><td colspan="2">Heterogeneous</td></tr>
<tr><td rowspan="2">Collaboration</td><td rowspan="2">Inter-language
Biochemistry
Nanoscience</td><td colspan="2">Fractionated</td></tr>
<tr><td>Boundary
Object
Cowrie shell
Zoology</td><td>Interactional
Expertise
Interpreters
Peer Review</td></tr>
<tr><td>Coercion</td><td>Subversive
McDonalds
Relativity</td><td colspan="2">Enforced
Galley Slaves
Use of AZT to treat AIDS</td></tr>
</table>

FIGURE 6.3 A general model of trading zones. From Collins et al. (2007).

collaborative or coerced? On the one hand, the interaction moves scientists toward a goal—further understanding particles and nuclei—that they have always sought, which might suggest collaboration; on the other hand, it was political necessity for the laboratory, stitched together because of the failure of a big science project, which might suggest coercion. When someone makes the claim that the collaboration was cooperative or coerced, who then is speaking and why? The collaboration was both cooperative and coerced at the same time, or neither; it arose from the scientists living in the midst of the scientific world, motivated by dissatisfaction, and using what tools they had to achieve what they could in pursuing their inquiries. They were making their way intelligently in an atmosphere whose elements were not separable into categories like "cooperative" and "coerced." Maintaining cultural heterogeneity is not always natural, and transforming it is not always slavery. The notion that all transformation of the boundaries of science is enforced is the product of a Forman-like postmodern conception of disciplinary boundaries.

What if interdisciplinary research, instead, were looked at from the perspective of its participants themselves, rather than from the outside? For someone joining an RHIC collaboration, say, it is not a matter of contributing a block of information to the project the way that a jigsaw piece contributes to the whole. Rather, it is a matter of working *with* other participants, oriented toward the practical realization of a goal. Being in such a project cannot be conceived of in terms of a space of disciplines or departments but is rather more like participation in a community, with the life of the community determining and altering its structures rather than the other way around.

6.3.3 The Immaterial Culture of Interdisciplinarity: Trust and Expertise

Interdisciplinary collaborations thus involve a matrix of intangible elements. To collaborate, you do not have to share the culture, or the same understanding, of the project on which you are collaborating; less tangible elements may come into play (Seligman et al. 2008, p. 8). All that may be required for one to help build or operate an X-ray machine may be things like a desire to help out. To be sure, this matrix and these less tangible elements tend to be drowned out by the task, the topic, the goal, and it is difficult to speak about something that is so easily overwhelmed by the discourse of facts and results. But these things are part of the atmosphere that allows us to inquire and act intelligently.

One of these elements is trust. Trust is a key, if often overlooked, concept in science. Trust here does not mean a moral virtue. Rather, to put it briefly, trust means deferring with comfort to others, in ways sometimes in our control, sometimes not, about a thing or things beyond our knowledge or power, in ways that can potentially hurt us. Trust, which has both a cognitive and a noncognitive dimension, is extremely important in different kinds of interactions within science and between science and society. Science depends on trust in the form of all those bonds of mutual cooperation that have to exist between scientific colleagues in their various roles. Shrum et al. (2007) note the importance of trust in interdisciplinary collaborations.

The correlate of trust is expertise; an expert is often the one to whom one defers to obtain knowledge on which one is dependent. Collins et al. (2007) describe "interactional expertise," or fluency in the discourse of a field without the ability to contribute, as a particular kind of expertise necessary for at least one of their four categories of interdisciplinary collaboration. One of their key examples is Steven Epstein's (1996) description of San Francisco AIDS activists, who collaborated with researchers. Shall we call this a collaborative or coerced interaction? Here, too, the inquiry's the thing, and the activists' recognition of the need for scientific expertise is behind the interaction. When there is no common inquiry—antinuclear activists versus a research reactor, say—and the atmospheres are fundamentally different, interactional expertise cannot happen. Expertise breaks down in the absence of trust and a shared life-world. Without that shared life-world, there is the possibility of reading the meaning of that expert advice differently—that the experts are hired guns, misguided, ignorant, ideologically or politically motivated—conspiracy theories thrive, and the value of expertise vanishes.

6.3.4 Fractionation

Many studies have discussed the fractionation of fields of knowledge under various rubrics: internal differentiation, cross-stimulation, clusters of specialization, hybridization, and so forth (Tanaka 2008, p. 24). Collins et al. (2007) note that while many fields, such as that of gravitational wave detection and, we might say, relativistic heavy ion research, appear from the outside to be coherent, when viewed more carefully they can be seen to be divided into numerous subspecializations with no move toward homogeneity—that there is discontinuity when looked at closely. They propose that this may well be the real state of all science—that it is like a surface that seems smooth to the naked eye, but turns jagged when magnified enough. "It may be that, when examined closely, what appear to be integrated networks of scientists are really conglomerations of small groups bound together by rich interactional expertises" (Collins et al. 2007). They add, "One can always choose to 'zoom in' on any area of social life and, as the scale increases and ever more detail is exposed, as with a polished metal surface, what appeared smooth turns out to be jagged." In this event, they claim, scientific disciplines are like "fractals" whose structure is reenacted at every scale.

This interesting observation raises many questions. Is the fractionation of the same type throughout science, or does it vary throughout the phases of a construction project like that of a giant telescope or accelerator? And is there a limit to this behavior? Is research not "quantized," in the sense that a basic unit of research is the researcher, who builds expertise and competence by being cultivated in a particular area in a particular kind of research context? That person's career and advancement are also determined by rewards and institutional structures, which also seek to keep that person focused on individual areas. This focus on individual areas may thus be for social reasons—prestige, advancement, coping with the administrative structure. The researcher may eventually join with others in a goal met jointly, but begins by mastering one area or set of areas. Research involves not the achievement of a collective oneness but an endless task of integrating and splitting in a communal context.

6.4 Integrative Systems

The interdisciplinary research described above involves regions of knowledge and interactions between researchers. A different, though related, set of issues is raised when such knowledge is considered as arising within *integrative technological systems* that have been planned and promoted for practical applications. Now not only scientists but also administrators, politicians, evaluators, lawyers, and businessmen are involved in a nexus that Klein (this volume) calls transdisciplinary. A classic example is the Biopolis, established in Singapore, to promote not just medical research but also interactions with clinical applications and to facilitate the construction of a proper legal and economic infrastructure in which these applications will thrive. Biopolis has now been joined in Singapore by Fusionopolis, a research complex whose focus is on materials science.

Rüdiger Wink, for instance, refers to *innovation systems* and *integrative technologies*, by which he means "the systemic linkages between single innovation networks to enhance interaction of knowledge between the networks and their members and to increase the innovative capacity of the whole system" (Wink 2008). These systems connect abstract and theoretical scientific knowledge with "incumbent technologies"; involve "no clear boundaries between basic and applied science" insofar as new scientific knowledge can be plugged directly into new goods and services; and involve scientists serving as researchers, managers, and entrepreneurs. Such systems encompass the "whole knowledge production process," or the entire "knowledge value chain," extending from knowledge production through review and exploitation, in which the laboratory is only a part—but the rest of the system/chain affects what happens in the laboratories. Wink stresses the importance of *gatekeepers* as the connections between the elements of this process—the parallel to interdisciplinary research—and notes facilitating factors such as *cognitive, social*, and *organizational proximity*.

An example of integrative systems at work is human embryonic stem cell research. Here a science with a variety of direct and urgent practical applications is subject to a variety of regulations that cannot be ignored in research, and with huge effects on laboratory research, involving ethics, capital markets, intellectual property rights, and so forth. Different countries have different integrative networks for dealing with stem cell research with different kinds of legal frameworks, and different kinds of links to industries, in play that affect how research takes place. A country's integrative networks may facilitate or hinder its ability to link with networks in other countries.

Justus Lentsch, meanwhile, discusses the need to develop better *boundary institutions* that are accountable both to scientists and to policy makers (Lentsch 2006). Frequently cited examples of institutions with such *dual accountability* include the Dutch Sector Council Model, the European Food Safety Authority, and the European Environment Agency.

6.5 Interactional Networks

Even more issues are raised when the public reaction to an integrative network is taken into consideration. A vast distance exists between the knowledge about a subject that circulates in a laboratory and the knowledge about the same subject among the public. A gap exists between the "load," as it were, born by the discourse in the two cases (Crease 2000). Connecting the two requires a kind of "impedance matching," in which the load is stepped down. This cannot be a one- or two-step process—education plus science popularization, say—but requires an entire spectrum of *interactional networks* between discourses with different loads. Without it, in public controversies with a technical dimension, positions become not argued but dramatically presented by people who think in slogans and communicate in images.

6.6 Conclusion

The physical sciences present excellent case studies of interdisciplinarity, its problems, and its prospects. Interdisciplinary research in the physical sciences is a particularly interesting case because of the amount of experience, the practical challenges, and the theoretical issues it raises in connection with science and its practice. Theorizing about interdisciplinarity can involve considerable posturing and self-congratulation. The physical sciences present clear examples of the inheriting, adapting, and transforming of disciplines—which can transform not only our understanding of science but also of all research. Interdisciplinary research is not simply changing science—its disciplines and the boundaries between them—but forcing the question of what science itself is. Its boundaries are shifting, in ways that make us mindful that it could have been otherwise, and doubtless will change still more in the future. And interdisciplinary research in the physical sciences, its integrative systems and interactive networks, is becoming ever more important to the welfare of the planet, making its study essential.

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CHAPTER 7

INTERDISCIPLINARITY AND THE EARTH SCIENCES

Transcending Limitations of the Knowledge Paradigm

VICTOR R. BAKER

7.1 Interdisciplinary "Dilettantism"

A number of years ago I made a presentation to a group of planetary science researchers on the geology of ancient water-related features on Mars. The talk outlined new research from ongoing planetary missions, but it also placed these discoveries and controversies in the context of historical arguments over similar issues. Moreover, the seminar discussed philosophical problems arising from differing scientific approaches to the understanding of the geological and hydrological evolution of Mars.

The audience for this talk included many young scientists from universities and government research laboratories. Also attending, however, was a visiting senior scientist from the Czech Republic, who later wrote about the experience. He found the seminar quite surprising because, while it was not unusual in Europe for science presentations to include perspectives on history and philosophy, he had not previously seen such a talk during his extended visit to the United States. Asking for opinions from several of the young scientists attending the talk, he received comments along the following lines, "Yes, we know this lecturer. He commonly gives presentations much of which will likely be very useful to our scientific work. However, he also mixes in a bunch of philosophical and historical stuff, which, while occasionally entertaining, will be of no use for advancing our scientific careers."

Scientific careers increasingly depend on positive outcomes from peer reviews of grant applications and successful editorial decisions on manuscript submissions to highly cited journals. Judgments by promotion committees, department heads, and deans depend on standards developed within established disciplines. Spreading one's professional activities across multiple disciplines leaves one open to charges of doing science that is "soft," "lacking in depth and/or rigor," or "spread too thin" and thereby deficient in demonstrating the scholarship expected for accountability standards of accomplishment and expertise. Thus, the

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young scholar who strays from disciplinary standards risks being perceived by colleagues as engaging in mere "dilettantism," that is, treating important matters of science in an amateurish manner.

By being inherently interdisciplinary, Earth scientists and the Earth sciences in general are as a whole vulnerable to this sort of judgment. In one example, a paper published in the journal *Science* was deemed irrelevant to the official promotion evaluation of an economic geology faculty member because the paper concerned logic, epistemology, and public policy. In another example a unit head refused to sign off on a research proposal by a very senior and accomplished geochemist because the proposed research concentrated on bacteriological, not geochemical questions.

At my own university there are interdisciplinary programs that have no equivalents at other universities. Nevertheless, the board of regents requires the performance evaluations for these units to include comparisons to equivalent units at other institutions. Since there are no such equivalents, a problem is created for unit accountability, not by the quality of the scholarship, but by the arbitrary protocol for unit evaluations. Should this problem be addressed by criticizing the units—or by throwing out the disciplinary assumptions underlying the protocols? These issues merely illustrate internal impediments to achieving effective interdisciplinarity. However, there are even larger questions about how interdisciplinary science is to be conducted, particularly if that science is to be effective in benefiting humankind.

7.2 The Earth Sciences

Concepts arise out of the history of their inception, and they evolve through their subsequent application. The concept of a discipline arose from the need to classify the flood of information produced by the newly evolving sciences of the modern era. This process began in earnest with the French encyclopedists of the eighteenth century, notably Denis Diderot (1713–1784). It was during the nineteenth century, however, that the idea of academic disciplines became ingrained within academia. This first occurred at German universities, and it eventually became codified into the familiar academic divisions found at today's colleges and universities. Up until the later nineteenth century, considerable academic effort was expended on the classification of the sciences. Though today such classification is hardly a thriving branch of academia, uncritical vestiges of this antiquated activity, as noted above, remain in place as standards of judgment for the certification of expertise.

Conventional disciplinary classification of the sciences involves four main groupings: (1) the natural sciences (e.g., physics, chemistry, biology, geology), (2) the formal sciences (e.g., mathematics, logic), (3) the social sciences[1] (economics, sociology, political science, history), and (4) the applied sciences (e.g., medicine, engineering). The natural sciences are, in turn, split into physical sciences and life sciences. Problems immediately appear for various Earth sciences. Geography is both a social science and a natural science, with the latter split between life science (biogeography) and physical science (physical geography).

[1] My university places philosophy in its College of Social and Behavioral Sciences, something that is rare at other academic institutions.

Ecology, the science that studies interactions of organisms with their environment, combines aspects of life science with physical science.

The inherent interdisciplinary of the Earth sciences derives from the need to combine aspects of other disciplines into the practice of studying the Earth. For example, the Earth sciences necessarily apply methods from physics and mathematics (geophysics, physical geology), chemistry (geochemistry), biology (paleontology), and computer sciences (simulation modeling of climate change). All this interdisciplinarity has a number of consequences, including uncertainty as to how Earth scientists should define themselves. Empirical evidence for this is provided by disagreements over how to name Earth science academic departments (Table 7.1). Many Earth science departments have changed their names multiple times, perhaps reflecting a sense, contrary to the nominalism that supposedly underpins positive science, that there is a kind of reality to the names that are applied, and that the nature of Earth scientific endeavors is changing with time, thereby requiring new names.

Another consequence for the inherent interdisciplinarity of the Earth sciences is the perception that their incorporation of knowledge from "more basic" scientific disciplines is generally limited to the less rigorous and softer components of those disciplines. Thus, in contrast to cosmology, which incorporates cutting-edge physics and mathematics into its interdisciplinary formulations, the Earth sciences mainly apply eighteenth-century principles of Newtonian mechanics and differential calculus. Does this mean that the Earth sciences are merely derivative from their constituent disciplinary branches of knowledge? Moreover, given the limited sophistication of that derivative knowledge, is this not indicative of scientific immaturity? Finally, does this mean that the Earth sciences really just "reduce" to the more rigorously advanced disciplines of which they are composed?

Interdisciplinarity suffers from a kind of "pop" philosophy that holds some sciences to be more "basic" than others. Related to this is the notion of "rigor" that is commonly attributed to particular disciplines. These vague concepts are used to define hierarchies that rank or order the sciences from those that are "basic," "rigorous," and/or "hard" to those considered to be "derived," "descriptive," and/or "soft." An example is the sequence that proceeds top-to-bottom from mathematics to physics to chemistry to biology (particularly molecular biology) to Earth sciences to the social sciences (with economics at the top), and eventually to more human endeavors that fail to get recognized as sciences at all. Of course, the notion that mathematics provides scientific "rigor" suffers from the fact that mathematics does not in itself need to have any relation to nature at all. Physics, as the most mathematical of the natural sciences, derives its "rigor" by appropriating for its study those parts of nature that can be simplified sufficiently for mathematical expression. This leaves the more complex, that is, difficult, or "hard," parts of nature to be studied by those sciences that are lower on the hierarchical scale. Earth sciences, of course, deal with all the meanings of hardness, including things that are complex, rather than simple, as well as the concrete parts of nature that are rock hard, as opposed to being very "soft" transitory wisps of thought about the world.

Hierarchies are embedded in the assumptions that are used to achieve them. One can get a completely different hierarchy of the sciences by placing at the top those sciences that deal with the most complex and difficult issues for humankind's relationship to the natural world. Alternatively, instead of a downward scaling from basic to derived sciences, one might envision an upward branching from a base that is intrinsic to the world in which humans find themselves. The famous British geologist Arthur Holmes proposed this kind of disciplinary

Table 7.1 Some Earth Science Departmental Names Associated with Natural Sciences Schools and Colleges

Department Name	Schools
Geology	University of Maryland, Portland State University, University of Kansas
Geosciences	Pennsylvania State University, Princeton University, University of Arizona, Virginia Tech University, Stony Brook University
Geological Sciences	Stanford University, University of Colorado–Boulder, University of Oregon, University of Texas at Austin, University of Florida, University of North Carolina–Chapel Hill
Geology and Geophysics	University of Wisconsin–Madison, University of Utah, Louisiana State University, University of Wyoming, University of Alaska–Fairbanks, Yale University
Geophysics	Colorado School of Mines, Stanford University
Earth Sciences	University of California–Santa Barbara, Rice University, University of Oxford, University of Cambridge, University of Michigan, University of Southern California, Dartmouth College
Earth and Environment	Franklin and Marshall College, Boston University
Earth and Environmental Science(s)	Columbia University, University of Pennsylvania, Rensselaer Polytechnic Institute, Boston College, Vanderbilt University, Rutgers University
Earth System Science	University of California–Irvine, Stanford University
Earth and Oceanic Science	University of South Carolina, Duke University
Earth, Ocean, and Atmospheric Science	University of British Columbia, Oregon State University, Florida State University
Earth and Planetary Sciences	University of California–Berkeley, Harvard University, University of California–Santa Cruz, Tokyo University, University of New Mexico, Johns Hopkins University, University of California–Davis, Northwestern University
Earth and Space Sciences	University of Washington
Earth, Planetary, and Space Sciences	University of California–Los Angeles
Earth, Environment, and Planetary Sciences	Case Western Reserve University, Brown University
Geology and Planetary Science	University of Pittsburgh
Geological and Planetary Sciences	California Institute of Technology
Earth and Space Exploration	Arizona State University
Earth and Atmospheric Sciences	Cornell University, Georgia Tech University, University of Nebraska–Lincoln

(*continued*)

Table 7.1 Continued

Department Name	Schools
Atmospheric Sciences	Colorado State University, University of Arizona, University of Washington, University of Utah, University of Illinois
Atmospheric and Oceanic Sciences	University of California–Los Angeles
Marine, Earth, and Atmospheric Sciences	North Carolina State University
Oceanography	University of Washington, Texas A & M University, University of Hawaii at Manoa, Dalhousie University
Hydrology and Atmospheric Sciences	University of Arizona
Land, Air, and Water Resources	University of California–Davis

classification in his classic 1945 textbook *Principles of Physical Geography*. Modifying Holmes's vision slightly, one can put Earth itself at the base (not just the physical planet, but all the life within and on it, including humankind). From this base one moves upward to sciences that deal with Earth's spatial and temporal domains: geography and geology. On the geological side there is split between historical (time-bound) dimensions and physical (causal) domains. The historical domain clearly involves the evolution of life that is studied in paleontology, but which also is key to all biology. On the physical side are the causal processes involving rocks (mineralogy and petrology), their relationships (structural geology), the planetary surface (geomorphology), the interior (geophysics), the atmosphere (meteorology and climatology), the hydrosphere (hydrology and oceanography), and ultimately the extraterrestrial (astronomy and planetary science). All these branches spread outward toward generalities involving the realms of physics, astronomy, and molecular biology.

7.3 Epistemic Interdisciplinarity

We have seen that academic disciplines involve focused study in a particular academic field, and that they derived from a history that produced a parsing of the various branches of human knowledge. This focus on "knowledge" appears in the very word "science," which derives from the Latin *scientia*, meaning "knowledge." Classically, the meaning of "knowledge" traces back to ancient Greece and writings of Plato, who viewed knowledge as "justified true belief." Modifying this definition to specify the sound justification that is presumably provided by science, one arrives at the commonplace modern view that science acts as a repository well-justified true beliefs, and thus provides the source of what is held to be the expertise that is needed to underpin effective decision-making.

The power for achieving positive action in a democratic society, a goal considered to be the role of politics, is commonly presumed to require a basis in well-justified, true beliefs. Given that politicians have not demonstrated themselves to be trustworthy generators of such knowledge, it is the common view that the expertise needed for wise societal action must come from science, viewed as the premier source of knowledge. Following from that, a sizable portion of public treasure can justifiably be allocated to the scientific enterprise in support of this mission.

Despite its dominance in the realm of public policy the science-as-knowledge concept leads to a number of problematic consequences. According to the classical definition of knowledge, emphasis is placed on epistemological issues for achieving truth and for the justification of that truth. For the intrinsically interdisciplinary Earth sciences this science-as-knowledge assumption necessarily involves epistemic interdisciplinarity.

7.4 An Example of Earth-Science Interdisciplinarity—The Study of Floods

Floods are clearly an Earth phenomenon worthy of study as an interdisciplinary Earth science. They are natural processes of great importance in the evolution of landscapes, the operation of the hydrological cycle, and the emplacement of sedimentary records. They also can pose immense hazards to humans and their property. Nevertheless, there is no academic discipline devoted to the study of floods per se. If there were such specialty it might be called "plimmyrology" which combines the Greek words for "flood" (*plimmyr*) and "study of" (*logos*) into a rather ugly unity. Instead of a single discipline for the study of floods there are multiple disciplines that deal with floods, though with different purposes and perspectives, and generally as secondary concerns relative to other issues. Various flood-related disciplines include flood hydraulics, which deals with the physical equations of flood water flows; flood engineering, which deals with applications of flood science to problems of hazard evaluation and the design of protective works; flood hydrology, which emphasizes the calculation of flood frequency for the estimation of risk; flood geomorphology, which deals with the effect of floods on landscapes; and flood geology, which deals with interpreting the history of ancient floods and their role in the geological history of the planet. Each of these disciplines brings its own perspectives to flood studies, but also its own limitations in regard to how it relates to other disciplines, and even in how it relates to the nature of floods.

7.4.1 "Dilettantism" in Flood Science

In the early 1980s I attended a seminar by a prominent flood hydrologist dealing with the problem of alluvial fan flooding in the American West. The speaker derived a series of equations that predicted the risks posed by flooding to life and property as well as providing the basis for mitigation adjustments that might include protective structures and hazard zonation. His viewpoint was clearly that of hydraulic engineering, a branch of applied physics that treats river basins as hydraulic machines driven by physical laws of force and resistance that have universality of application and certainty in their predictions, relative, of course, to various assumptions. Hydraulic engineering exemplifies the "rigor" and "depth" that can be achieved by a "hard science" in which the expertise of the practitioner can readily be certified by disciplinary standards.

At the end of the talk I asked the speaker how he recognized the alluvial fan situations to which his equations applied. This question obviously required thinking about geomorphology, the science of landforms such as alluvial fans, the processes associated with landforms, and the modes of recognizing preserved evidence of those processes. The speaker answered my question by citing a well-regarded textbook on fluvial geomorphology, thereby implying that the general descriptions contained therein would assure the recognition of the alluvial fan situations to which his equations would apply. Of course, there are many kinds of processes that can occur on alluvial fans, and every alluvial fan is subject to a combination of these processes, depending on the rock types and structures in the fan source areas, the local climate, weathering processes, and even regional tectonic history. All these function together in ways that are unique to every alluvial fan and therefore cannot be outlined as generalities in a textbook.

This is clear example of epistemic interdisciplinarity involving science-as-knowledge. It also reveals a profound naïveté in regard to complexities of Earth processes. Earth's realities dictate that all alluvial fans are different; each alluvial fan develops from a complex of processes that range from pure water floods to highly viscous debris flows, all of which exhibit very different kinds of physical behavior. Alluvial fans are always evolving through real time in a progressive, not strictly random, manner. While the history of this change can be read in the details of the landscape and reasonably be extrapolated to likely future conditions, it cannot be accurately predicted from an arbitrary set of generalized equations chosen on the basis of necessarily simplifying assumptions.

This example illustrates epistemic interdisciplinarity because the hydraulic engineer is indeed using knowledge from other disciplines, but is doing so from the point of view of a particular knowledge discipline, that of hydraulic engineering. Hydraulic engineering is concerned with the design of hydraulic structures, such as large dams. Since these structures can be at risk from extremely large floods, it is necessary to generate numeric measures of risk that can be used to achieve designs within some level of tolerance. However, given the rarity of extremely large floods that would pose very great risk to these structures, the prediction of flood probabilities for risk analysis must entail assumptions, nearly all of which are highly problematic. Despite this limitation, however, these problematic assumptions continue to be made because of the necessity to make engineering design decisions in the light of what is presumed to be a lack of information on extremely large, rare floods. This presumption of ignorance about extremely large, rare floods is not science (ignorance being the lack of knowledge or information); one learns nothing when one presumes in advance that there is nothing to learn. Moreover, as discussed below, data on extremely large, rare floods is exactly the kind of information that is provided through another discipline: the geological study of evidence from the well-preserved effects of such floods.

Another kind of interdisciplinarity arises not from the questions that are posed to nature, but from the questions that are posed by nature. In the alluvial fan case, nature's questions are posed by the real-world existence of a landform belonging to a highly complex class of phenomena to which has been attached the vague label "alluvial fan." The practitioner of hydraulic engineering noted above looked to a geomorphology textbook as a source of knowledge, in essence treating the results of past inferences generalized in that textbook as facts that could be assumed in getting on with the mathematical expressions needed to generate quantitative predictions. This example is particularly relevant because modern flood hydrological science emerged from origins as an appendage to hydraulics and hydraulic engineering (Klemes 1986). However, to be a true interdisciplinary science of floods, flood hydrology cannot restrict its purview to that of hydraulic engineering. To do so, in spite of all the rigor and predictive emphasis of that discipline, is to deal with the reality of floods by merely toying with the subject matter. Klemes (1986) has termed this "dilettantism," applying that label in the context of science-as-knowledge. The problem is even worse, however, because, as noted above, any flood hydrology that makes this assumption of ignorance is radically antiscientific. Above all and most fundamentally, science, as process of inquiry, rather than a repository of knowledge, must embrace openness of inquiry as an absolute requirement. By claiming ignorance as a matter of assumption, much of conventional flood hydrology cuts off inquiry and thus kills any chance for productive science in regard to understanding extremely large, rare floods.

7.4.2 Paleoflood Hydrology as a "Transdiscipline"

When nature presents the questions, the scientist must seek the methods from those disciplines that can most effectively deal with what nature presented. This is more than just an application of knowledge. It is an interaction with the messy details of nature to produce new understanding. In this spirit, a new approach to the scientific study of floods began to emerge in the middle twentieth century. Dubbed "paleoflood hydrology" (Kochel & Baker 1992) this approach provides an example in which disparate branches of the Earth sciences are combined in a kind of nature-directed "transdiscipline" to advance scientific understanding.[2] Paleofloods are past or ancient floods whose characteristics are indicated by means of natural recording processes. The scientific "transdiscipline" of paleoflood hydrology arose by combining geological, hydrological, and hydraulic approaches to the study of flooding phenomena, and by incorporating recent technological advances in geochronology

[2] Klein (this volume) outlines the complex relationship of "transdisciplinarity" to the taxonomy of interdisciplinarity. Coined during the early 1970s, "transdisciplinarity" originally applied to the transcendence of disciplinary worldviews to achieve an overarching synthesis. Klein's example of anthropology construed as a transdisciplinary "science of humans" illustrates how a transdisciplinary "science of floods" is embodied in "plimmyrology" with its critical component of paleoflood hydrology. Klein further describes how current trends have involved diverse applications of the transdisciplinarity concept to multiple themes, including those of (1) traditional movements seeking unifications of science-as-knowledge (e.g., Wilson, 1998a); (2) critical transgressions across disciplinary boundaries to crate new theoretical paradigms; (3) holistic frameworks like general systems theory, Marxism, and policy sciences that transcend the narrow scope of disciplinary worldviews; and (4) emphasis on problem solving that commonly incorporates collaborations among academics with industry, social actors, "stakeholders," and other nonacademics to achieve workable solutions to society's most pressing problems. Despite these multiple meanings, in this essay I adopt the term "transdisciplinarity" because its vagueness affords an openness of inquiry to new forms of synthesis that allow for transcendence beyond the science-as-knowledge paradigm that impedes the most productive forms of interdisciplinary interplay within the Earth sciences.

and hydraulic flow modeling to estimate the magnitudes and frequencies of paleofloods from evidence of their paleostages (Baker 2008, 2014).

Whereas interdisciplinarity transcends disciplinary boundaries by transferring knowledge and methods from one or more disciplines to another, it does so from the perspective or research framework of a receiving discipline. Transdisciplinarity, on the other hand, involves new perspectives that go beyond what may have been part of any of the disciplines involved. There continues to be disagreement as to whether these new transdisciplinary perspectives should emphasize the unification of knowledge, whether the scientific knowledge and/or methods should be extended to areas outside science itself, or whether some other combination should arise. Before moving on to these questions, more attention is given to the paleoflood example.

The scientific study of paleofloods derives from a long tradition in geology concerned with field evidence for ancient floods. The geological approach is both causal and historical, involving the recognition of various preserved signs or traces that can be interpreted by the experienced geological investigator as evidence for past flood processes. The geological investigator of floods works out a history of past flood events in much the same way that a history of past biological organisms is worked out through paleontological studies of their fossil forms. This history serves as a source of discoveries about the nature of the flooding, including its patterns in time and space.

Of course, this extension beyond the physics-based hydrological tradition led to criticism. The following critique appeared in a 1986 technical review[3] of a report to the International Union of Geodesy and Geophysics dealing with progress in paleoflood hydrology (Stedinger & Baker 1987):

> Imagine a solid-state physicist, organic chemist or other practitioner of "hard science" reading this manuscript . . . Shaking his head with sad amusement as he muses about how far the geologists still have to go before their field of study can properly be called science, he leafs through the final section of the manuscript and references. This wipes the smile off his face, for he discovers that these paleohydrological methods are being advocated, in all seriousness, for use in assessing the safety of dams and choosing sites for hazardous waste disposal.

These comments are reminiscent of a well-known assertion by Sir Ernest Rutherford: "All science is either physics or stamp collecting." This sentiment is true to the extent that Rutherford, or the anonymous "hard science" reviewer of the paleoflood hydrology paper, if they ever attempted to do some geology, would likely indeed perform an activity in a manner similar to that of "stamp collecting," thereby confirming their ignorance as to what it is to do geology. Physics is the natural science that makes maximal use of mathematics, but mathematics is a formal science, not a natural one. This makes physics the least natural of the natural sciences. Physics is the science that offers absolutely the least possible understanding of the real time of duration that is the subject of history, either human or natural; and while physics works wonderfully for expressing universal generalities that underlie fundamental aspects of natural processes, it also offers the least understanding of the complex web

[3] The review was anonymous, following the common practice of secrecy for the review of scientific papers, a practice totally at odds with the ethical norm of openness in scientific inquiry.

of causation that exists in the innumerable, messy, and constantly changing particularities of the natural world.

7.5 Transdisciplinary Earth Sciences?

The fundamental paradox of flood damages is that they continue to increase despite major advances in flood-science-as-knowledge, including the application of much quantification and mathematical modeling. Science continues to be used to justify immense public expenditures on flood mitigation. Flood damages do indeed partly correlate to the causative factors identified by scientific study, but there are much stronger correlations to the value of construction and other human activities in areas that can very easily be designated as potentially hazardous. Flood damages also correlate especially well to those rivers where the most money has been spent on infrastructure that is purported to "protect" against flood damages. The most expenditure has been on the Mississippi River, which continues to experience the most damage, and the second-most money has been spent on the Sacramento River, which experiences the second-most damage. If one rejects simplistic correlation as causation, namely, that research and its results cause the damages, then it might be hypothesized that something is wrong with the research program and its practical implementation.

These are issues that clearly transcend the disciplinary contexts in which flooding has traditionally received scientific attention. Thus, they are transdisciplinary in the vague sense being used in this essay, but let us see if some clarification can be achieved through more examples.

7.5.1 The Science/Policy Interface

Public policy continues to embrace the notion that decision-making should be based on the best possible "science," but this is science-as-knowledge. It typically employs quantitative models, and there is no question that the capabilities and power of this scientific resource are being very rapidly advanced through spectacular technological innovations. Moreover, there is also no question that the predictive capabilities of these models have immense appeal in a political system that is geared to invoking science, not as a process of adaptive inquiry, but as source of expert authority for claims that problems are being solved. There remains an immense question, however, as to whether the business-as-usual approach of providing the best possible science-as-knowledge to decision makers is resulting in the best possible policy outcomes. There certainly is evidence that our current paradigm of predictive modeling of environmental systems can lead to disastrous policy outcomes (Pilkey & Pilkey-Jarvis 2007; see also Vogel et al., this volume).

The science-policy-action paradigm is not working in regard to flooding. We have a national program of designating flood-hazard areas as a by-product of applying an insurance-based mindset of using of large-population statistics to assess risk to the insuring company—rather than to inform people in ways they can understand and ways that motivate them to take effective action. This manifests itself in the so-called hundred-year flood designation, which is a by-product of the hydraulic engineering approach to flood risk assessment. It is also an example of science-as-knowledge at its worst. The "hundred-year flood" can be calculated in a systematic way by universally applicable mathematical expressions, understood only by an elite of technical experts and conveyed through authoritative government pronouncements. It is an idealization that does not refer to any actual flood, and that has essentially nothing to do with real years. Instead, it is the inverse of an annual exceedance probability[4] that must be estimated by mathematical extrapolations that are necessarily based on highly questionable assumptions.

The contrast with paleoflood hydrology is striking. Paleoflood information derives its authority not from claims of mathematical perfection, but from the discoveries of natural recording of ancient (but very real) cataclysmic processes with obviously documented potential to cause harm. The commonsense recognition that what has actually happened can indeed happen again has much more potential to incur engaged and wise public response than does the invocation of abstract terminology that befuddles rather than informs.

7.5.2 Public Understanding/Education

The level of public understanding of the Earth sciences in the United States is totally antithetical to the importance of the Earth for human existence. This is evidenced by the media success in swaying pubic opinion to the view that there is a valid scientific controversy in regard to human activity as a causative factor in Earth's climate change (Oreskes & Conway 2010). This sorry state of affairs has been achieved by design. Our science education system is largely based on what Sir Karl Popper once termed the "bucket theory" (Popper 1979, p. 61). Imagine a student with a bucket instead of a head. The facts of science-as-knowledge are poured into the bucket, and output from the student can be measured and certified by testing for "science literacy"—as though science is something that one reads in textbooks as opposed to being an attitude engaged in by a community dedicated to searching for the truth in things. Moreover, the formula for science-as-knowledge is the nineteenth-century classification of disciplinary knowledge that has high school students taking coursework in hierarchical arrangement, with physics at the top, chemistry below, and so forth. The interdisciplinary sciences of Earth and environment are relegated to lower grades, as befitting their lower status in the flawed hierarchy of science-as-knowledge.

Students can only get beyond the limitations of science-as-knowledge (Popper's "bucket") by practicing science for themselves. In regard to the science of floods, they need to explore the effects of floods, to study the flood histories of their own towns, to see the effects of past flooding in their own areas, and to feel empowered to raise questions about what their communities are doing about floods. This is can be termed a "flashlight theory," wherein the student is empowered by scientific reasoning to illuminate the darkness.

[4] See Klemes (1987, 1989) for a discussion of how flood-frequency analysis introduces probability concepts that are contrary to both common sense and a scientific spirit directed at understanding the natural world.

7.5.3 Transdisciplinarity

The foregoing examples involve very timely "wicked problems." These may have high degrees of risk and uncertainty, as with the problem of extreme floods. There may be political and social issues, such as those arising from the lack of public understanding of science and the sorry state of science education. There are many other issues of current concern that need very timely attention, have disputed values, and involve considerable complexity in their scientific treatment. The Earth sciences are involved in many of these, including global climate change, environmental degradation, health and sanitation, societal vulnerability to natural hazards, sustainability, and so forth. All of these problems need highly creative solutions involving science that is very responsive to social concerns. The involvement of stakeholders is becoming essential for achieving effective action.

The term "transdisciplinarity" is increasingly being applied to such efforts (Bernstein 2015), and that term is also being applied to efforts at achieving a kind of unification of disciplines that extends beyond the sciences to the arts and the humanities. However, this is not the kind of unification that developed during the mid-twentieth century's "Unity of Science" program. A recent resurrection of that earlier unification quest appeared in E. O. Wilson's best-selling book *Consilience: The Unity of Knowledge* (1998a; see also Wilson 1998b). Wilson's enthusiasm for the spectacular advances in science-as-knowledge that are the by-products of scientific inquiry compels his vision for extending the web of causal explanation achieved in the hard sciences to the social sciences and even to the humanities. It is this ideal alignment of knowledge to which Wilson applies the term "consilience." Wilson's vision coheres with that of those who would promote a new kind of scientism, one that ultimately views science as knowledge and power. Sadly, this equating of science to scientism has led some scholars in the humanities to resist any such unification. One of the few philosophers to engage in debate on this issue is Richard Rorty, who observed, "it is not clear that our answers to . . . moral . . . questions will be improved by better knowledge of how things work" (Rorty 1998).

The unification associated with transdisciplinarity is not one in which some disciplines get reduced to others. Instead there should be a union that gets beyond the limitation of each discipline in generating that which is larger than the components of the union. Thus a transdisciplinary union would function more like the growth of a marriage than like the interdisciplinary borrowing and transfer from discipline to discipline. The Earth sciences are particularly well suited to participate in such unions. The continued welfare of humankind compels them to do so.

7.6 Conclusion

Interdisciplinarity is inherent to the Earth sciences. This commonly manifests itself through the science-as-knowledge paradigm. Though this paradigm has current ascendancy in regard to generating the expert knowledge that is converted for use in political/policy discourse, it is both limited and compromised by attitudes that restrict the full capability of science to relate to the natural world and to convey that relationship in a way that more effectively advances humankind. The developing concept of transdisciplinarity offers hope to remedy this problem by creating new scientific viewpoints through unions of multiple disciplines and through the participatory involvement of nonscientists in areas ranging from public policy to public education. An example of trandisciplinarity in the Earth sciences is provided by "plimmyrology," the science of floods, particularly in regard to its branch, paleoflood hydrology. Because of its focus on "letting the floods tell their own stories" paleoflood hydrology is truly transformative from flood hydrology that emphasizes the assumptions that permit theoretical statements and predictions to be made about flood phenomena. It thus represents a transitioning from an interdisciplinary study of floods to a transdisciplinary one, resulting in something different from what was in any of the constituent disciplines. Such transdisciplinary Earth science has profound implications for many issues of current societal concern, including the communication of scientific issues to the general public, science education in a democracy, and the future habitability of the planet.

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CHAPTER 8

INTERDISCIPLINARITY IN THE BIOLOGICAL SCIENCES

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The biological sciences have long benefited from the intellectual and pragmatic input of ideas and techniques from other disciplines, including medicine, chemistry, engineering, and mathematics. This chapter discusses the synergies that have emerged from the integration of these disciplines into the biological sciences, and uses examples to strongly advocate for such approaches. The reach of biology extends well beyond the sciences and technology into interdisciplinary interactions within the social sciences, arts, and humanities. Finally, interdisciplinary collaboration between various scientists, engineers, and mathematicians is not without its pitfalls and impediments, from both an individual and institutional perspective, so some potential hurdles to effective interdisciplinary research are outlined.

Curiosity about our biological surroundings and our role in the global biome predates the written word, as evident in ancient cave drawings at Lascaux (*c.* 16,000 BP) depicting the living world around the artist. Likely as ancient is the interplay between biology (as our ancestors perceived it) and other human endeavors, including religion, art, and the emergence of technology.

From these origins has arisen the discipline of biological sciences—a discipline that is fundamentally shaped by its interdisciplinary activities. Moreover, interdisciplinarity in the biological sciences is constantly shifting as new technologies and theories arise, evolve, and mature and—sometimes—fade away. Thus, the biological sciences, like many scientific disciplines, are constantly subjected to an "the interdisciplinary cycle" shown schematically in Figure 8.1. The merger of biology and chemistry, forming the new discipline of biochemistry (discussed below), is a classic example. Emerging as a new discipline (steps 4 and 5 in Figure 8.1), biochemistry is now a long-standing discipline that is itself going through another turn of the interdisciplinary cycle through its interactions with information science and nanotechnology. Similarly, the emergence of the discipline of bioengineering reflects the interdisciplinarity of biologic and engineering systems and communities.

This chapter presents a series of vignettes or case studies on how interdisciplinary studies between the biological sciences and other science and engineering fields have yielded new

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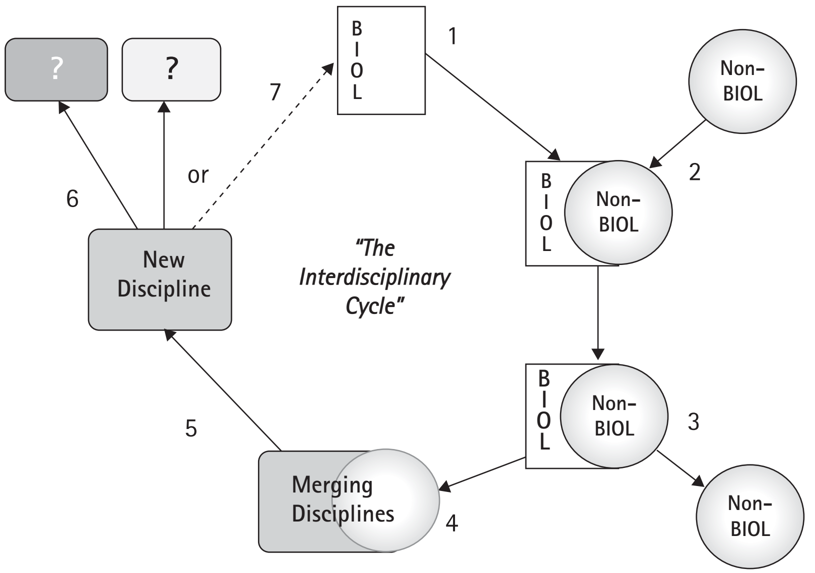

FIGURE 8.1 The interdisciplinarity cycle, in the biological sciences and other disciplines experiencing interdisciplinarity cross-fertilization. (1) A freestanding discipline such as biology regularly experiences the influence of nonbiological disciplines. (2) This comingling of ideas and techniques can ultimately be only fleeting (3), or it can result in a true merger of the disciplines (4). This new discipline, formed from the merger of biology and nonbiology (5), may eventually fragment into new disciplines, or can persist (6) to enter the interdisciplinarity cycle once again.

insights and practical products. It then discusses the advantages and challenges of undertaking interdisciplinary activity in the biological sciences.

8.1 Case Studies in Biological Interdisciplinarity

Biology has a rich history of interactions with the sciences, engineering and mathematics, as will now be considered.

8.1.1 Biology and Medicine

Biology and medicine have coexisted as intertwined disciplines for many millennia. The study of animals was most likely initially motivated by the need for their domestication as both a work force and source of nutrition. Artifacts from numerous ancient cultures provide evidence of observational studies and dissections. Aristotle and Erasistratus were among the first to publish the results of their experiments with living animals, and numerous others such as Aelius Galen, William Harvey, Stephen Hales and Antoine, Claude Bernard, and Louis Pasteur contributed to our emerging knowledge of biology.

It should be noted that up to the mid-nineteenth century, Western society embraced the belief in a "Great Chain of Being" ordering all of existence is a continuous natural hierarchy that placed man between God and all other animals. It was Charles Darwin who destroyed the belief in purpose in nature with the publication of *The Origin of Species* in 1859. By the turn of the twentieth century Ivan Pavlov used dogs to describe classical physiologic conditioning, and Sir William Osler developed the field of pathophysiology, creating a systematic way of understanding disease and health and their relationship to the biological sciences.

Primarily descriptive approaches dominated biology and medicine through most of the twentieth century. The subsequent growth of transgenic molecular techniques and model organisms (worm, fruit fly, zebrafish, mouse) allowed the artificial manipulation of molecular regulatory cascades, and the publication of the human genome. Recent discoveries that patterning genes are common to all of animal life from flies to humans, and that humans have fewer translated genes than a carrot, have emphasized the importance of comparative studies at the cell/molecular level for understanding both biology and medicine. As a result, contemporary biology is now expected, by analogy to physics, to generate a Periodic Table, formulate its own equivalent to $E = MC^2$, and develop a quantum mechanics of a predictive biology that relies less on time-honored empirical observation and much more heavily on prediction (Torday 2004). Based on this approach, the indirect methods of developmental and comparative biology, reduced to cells and molecules, have been used to connect the dots between first principles of physiology (e.g., homeostasis, acclimation) and the scientific basis for a more prediction-based medicine in the future (for review, see Torday 2013).

For centuries biology has used disease to leverage our knowledge and understanding of health, and vice versa, since all biologists had available was the outward appearance of an organism, as opposed to its genetic makeup. However, with the merger of genetics, molecular biology and physiology into the subdiscipline of genomics (the study of genes and their functions), we can now address the questions of health and disease as a continuum, based on genetic mechanisms as they apply to the relevant phenotypes. Along with the sequencing of the genomes of fishes, amphibians, and birds, it is now possible to exploit evolutionary-developmental biology to provide a Rosetta stone for helping to decipher the organic nature of disease. These advances have primarily arisen through the interdisciplinary comingling of basic life sciences and advanced medicine.

Evolutionary biology is fundamental to the biological sciences. Plugging genes and related phenotypes of interest into an evolutionarily robust model of animal development will allow us to decipher causes of human diseases (Torday 2013, 2014). Using this approach will allow biologists to see the continuum from adaptation to maladaptation and ultimately to disease. Such a perspective would finally offer a scientific basis for monitoring health independently of disease, ushering in a new era of preventive medicine. The key to such an approach is to identify the developmental cellular and molecular mechanisms that are fundamental to an organism's structure and function. Such studies are conventionally conducted by developmental biologists. Unfortunately, they only rarely involve biologists familiar with comparative, phylogenetic analyses across species. As a result, collaboration primarily occurs through the passive capture of data in the biological and medical literature that examines the development of phenotypes at the cell/molecular level. A number of national and international meetings have fostered more disruptive approaches involving developmental biologists and medical researchers, and a website (http://evolutionarymedicine.labiomed.org/) has been established to draw attention to this unconventional, but biologically sound and effective, interdisciplinary approach.

By systematically reducing complex traits to their genetic phenotypes developmentally across species, and by then sharing this vast amount of data via public databases, biologists will ultimately be able to unravel complex physiologic principles relevant to both biology and medicine. There are, of course, dangers in unmitigated reductionism, such as the failure to identify emergent properties that result from the interactions across components and levels. However, the success of a reductionist approach as one of many concurrent approaches shows great promise in medical advances.

The discipline of biology is on the verge of a sea change in the interactions between biology and medicine, if only it can utilize the huge data sets being created (via exploiting yet another interdisciplinary field—bioinformatics). By abandoning the old paradigm of descriptive biology, and moving into a mechanistic paradigm based on evolutionary principles, it may be possible to progress toward an era of predictive biologic science. This will enable biologists to address counterintuitive aspects of biology such as why the lens of the eye is composed of digestive enzymes, or why the lung is a hormone-responsive endocrine organ. With the anticipated interdisciplinary activities between predictive biology, predictive medicine, and technology (Torday, 2013), society's burden of chronic diseases may be significantly diminished.

8.1.2 Biology and Chemistry

One of the oldest and most productive interdisciplinary amalgamations within the life sciences is that of biology and chemistry into "biochemistry." At the heart of biochemistry is the study of the organic (carbon-containing) molecules and their chemical reactions within living systems. Biochemists today may not readily imagine themselves as interdisciplinary, yet their work bridges both the living and physical sciences.

That biochemistry is now less frequently thought of as at the interface of two disciplines is due in large part to its maturation as a discipline in its own right over the last 150 years. In fact, by the mid-twentieth century, entire departments of biochemistry were commonplace among many colleges and universities, where none had existed 50 years earlier.

The early history of biochemistry developed from the general concept that living materials catalyze chemical reactions. Consider studies of the fermentation process by yeast. Most of the early research was carried out in the late 1800s and early 1900s by scientists trained as chemists. Indeed, Eduard Buchner received the Nobel Prize in Chemistry in 1907 for his pioneering discoveries of the biochemical fermentation of sugar by cell-free systems, a clear recognition of the emerging science of "biological chemistry."

The popularity and power of biochemical approaches led to widespread exploration of biological systems where chemists, familiar with properties and analysis of organic molecules, sought to work with biologists experienced in physiology. This quest for understanding the mechanisms that drive biological systems has been the major driver for the emergence and maturation of biochemistry. Indeed, numerous major discoveries have been made possible through the interdisciplinary research of biochemistry, including the identification of:

- the structural features of macromolecules such as DNA (containing an organism's gene sequence, RNA (involved in replication of DNA), and proteins.
- the basis of enzymes, which facilitate metabolic reactions.
- the mechanisms of photosynthesis for conversion of light to chemical energy.
- the machinery of cellular respiration and membrane transport, for energy conversion and nutrient and waste movement in and out of the cell.
- the genetic code, whereby variations in the sequence of just four nucleotide bases universally explains the nature of proteins from bacteria to human.
- the basis for protein synthesis and turnover, for the production, regulation, and recycling of cellular machinery.
- the enzymes that regulate gene expression.

Since 1901, at least 35 Nobel Prizes in Chemistry and many more in Physiology and Medicine have been awarded for discoveries in biological chemistry, illustrating the tremendous rewards of working at the interface of chemistry and biology. Many of these discoveries have led to entirely new fields of interdisciplinary research. For example, out of the structural determinations of DNA, RNA, and proteins has developed the new discipline of structural biology; out of the enzymology of transcription and the genetic code has arisen the discipline of molecular biology. These two newer disciplines, much like the newly emerging area of systems biology, have been driven by the scope of the biological questions, but have depended on the contributions of scientists from many disciplines—including mathematics, computer science, chemistry, biology, and physics.

Interdisciplinary collaborations in the life sciences are most successful when the overall outcome is greater than the sum of its parts, and when all collaborators have a vested commitment in, and benefit from, that outcome. Consider comparative metabolomics—essentially the simultaneous profiling and quantification of all metabolites from a tissue or cell-type. This has analytical biochemistry at its base, but on a high-throughput, massive scale (many thousands of chemicals components). These types of experiments have required the development of sophisticated mass spectrometry-based instrumentation, the know-how for sample preparation, the expertise in separation technologies and robotics, the computational capabilities for data analysis, and someone to ask the relevant questions. Success depends on contributions from chemistry, biology, computer science, mathematics, and instrument design and engineering, and could not be achieved without any one of these components.

Biochemistry continues to evolve as an interdisciplinary activity. This is evident now with the era of everything "omics." The areas of genomics, proteomics, metabolomics, and so on, are an extension of the concept of understanding gene function, but on a genome or system-wide scale. With the rapidly advancing tools for analyzing DNA sequences, monitoring gene expression, identifying proteins, and quantifying metabolites, information is being gathered on an enormous scale.

Instead of an individual research laboratory experimentally addressing the function of a single gene over many years, teams of scientists are attempting to understand biology from an entire "systemswide" approach. This requires expanded capabilities orders of magnitude greater than those of two decades ago, when the first gene sequences were being collated in a database called Genbank. For example, as of April 2015, there were over 1 trillion bases of nucleotide sequence information archived in the Genbank and whole genome sequence

(WGS) databases. Accommodation of these increasing amounts of gene sequence, gene expression, protein structure, and metabolic data requires new computing power, expertise in predictive programs, powerful statistical methods, and computational algorithms. Questions can now turn to the functions of thousands of genes, proteins, and metabolites at once, helping to address everything from human health to agricultural production. These grand challenges require the collaboration of scientists with expertise in many disciplines in addition to biochemistry, and will involve tools and languages yet to be developed; but it is certain that interdisciplinary activity across traditional boundaries of science and engineering are the way forward.

8.1.3 Biology and Engineering

The relationship between biology and engineering is both intuitive and ancient. For example, Leonardo da Vinci was a prototypic artist/inventor/anatomist/engineer, whose studies on human form and function revealed the interdependence between biological processes, biomechanical function, and physical forces. Da Vinci showed us the great potential in the marriage of biology and mechanical functions. Indeed, modern engineering disciplines now encompass a broad matrix of biological topics, including developmental biology, bioenergetics, biomechanics, biomaterials, artificial intelligence, and bionics related to the development of artificial organs (Kurzweil 2005).

Yet the marriage between biology and engineering is neither easy nor automatic. Consider the comments of Fung et al. (2001) in his classic engineering text, *Foundations of Solid Mechanics*:

> Engineering is quite different from science. Scientists try to understand nature. Engineers try to make things that do not exist in nature. Engineers stress invention . . . Most often, (engineers) are limited by insufficient scientific knowledge. Thus they study mathematics, physics, chemistry, biology and mechanics.

Unfortunately, the inverse is not true—biologists, who also are often limited by insufficient knowledge, are not (yet) drawn in great numbers to study engineering. Yet, many biological processes occur within biophysical environments that are dynamic and rapidly changing. Analytic engineering principles and paradigms have been developed and applied to investigate and quantify many of these dynamic interrelationships, and emerging biology-engineering interdisciplinary partnerships are now poised to take advantage of them. Here we consider a few highlights of the unique opportunities and insights that have gained through the interface of biology and engineering.

Our current understanding of the developmental biology of the heart and blood vessels has been substantially influenced by interdisciplinary interactions between biologists and engineers. One of the most fundamental processes during vertebrate development is the growth and remodeling of the embryonic heart from a cluster of undifferentiated mesodermal cells to a multichambered organ with functioning unidirectional valves, a specialized conduction system for electrical impulses, and optimized blood flow to correctly direct deoxygenated and oxygenated blood to the tissues. Complex processes of heart tissue formation, including how heart cells, tissues, and structures (chambers, valves) grow and change, initially quantified by developmental biologists and physiologists, have now been analyzed by bioengineers. In fact, cardiovascular physiologists working with bioengineers can now actually visualize previously only theorized forces in the wall of the beating embryonic heart. This interdisciplinarity partnership has provided new understanding of how the quantifiable mechanical forces of sheer and strain in the heart walls actually help regulate cardiac growth and remodeling during normal development and in response to disease states. In fact, the interdisciplinary interactions of developmental biology and engineering used so effectively in cardiovascular biology have now been expanded to provide relevant insights and identify novel questions across an extremely broad landscape of developmental and comparative biology, ranging from protein configurations to whole embryo structure.

Regenerative medicine (the creation of replacement tissues and organs) is another example of the emerging products of interdisciplinary collaborations between biologists, physicians, and engineers. By exploring developmental processes in tissue and organ generation, bioengineers have developed new technologies for the design and fabrication of biomaterials (materials that can become part of or even replace original tissues). Bioengineering approaches have also led to a large potential commercial market for therapeutic substances produced by biological means—for example, vaccines and novel small molecules.

Such insights have led to the rapid expansion of regenerative medicine. In fact, organs and tissues (e.g., heart valves and engineered cardiac patches) generated in vitro ("in the test tube") have approached the critical phase of clinical trials. At the cellular and molecular levels, biologists and engineers are contemplating the creation of nanomachines that are injected into the blood stream of a patient, travel to their targeted tissues, and then carry out a specific suite of activities that can include actually permanent assimilation into the tissue. Of course, ethical issues arise from regenerative medicine, with uncontrolled extrapolation leading to the specter of "Borg-like" creatures where the boundary between human and machine is blurred.

Biologists have increasingly taken advantage of the powerful computational algorithms developed by engineers to generate predictive models of complex biological processes and systems. Ultimately, such models can serve in place of costly or impractical experiments. Multiscale models have been described for a variety of biological functions at the cellular and tissue levels, as well as limb development, and whole organ models such as the heart and circulatory system. In 2007, the National Science Foundation deemed models of the functioning, living cell and corresponding cell networks a grand challenge for the twenty-first century (Omenn 2006). Combining advanced mathematical, statistical, and training algorithms with biological data mined from hundreds of publications (dating as far back as 1962), an interdisciplinary research team successfully developed a predictive model of the life cycle of the bacterium *Mycoplasma genitalium*. The future of such biological modeling will require extensive collaboration and cooperation between mathematics, computer scientists and engineers, and biologists.

Successful collaborations between biologists and engineers are being catalyzed by a targeted expansion of funding by the National Institutes of Health, the National Science Foundation, and numerous other US foundations that support interdisciplinary teams. But even as collaborations that lead to advances in health are expanding, there is also a great deal of attention being paid to potential military applications resulting from interdisciplinary activities between biologists and engineers. For example, the exoskeleton of invertebrates such as insects and crabs is being studied with a view of providing an external "exoskeleton" for soldiers. This external, motor-driven scaffolding would allow them not only to carry more gear but potentially also to be remotely activated to march wounded soldiers out of danger.

Interdisciplinary collaborations between engineers and biologists often revolve around mathematical analyses and the limits of available computational infrastructure. We now turn to the highly productive collaborations between biologist and mathematicians.

8.1.4 Biology and Mathematics

Biology, as a quantitative science, has always depended heavily on mathematics. Collaborations between biologists and mathematicians, as a focused area of research, began in the early twentieth century with the study of disease transmission (epidemic models), population dynamics, and genetic frequency models. Building on this foundation, tremendous advances have been made through mathematical methods in almost every area of biological research, especially with respect to modeling biological processes. Agent- or individual-based models, supported by increased computational capabilities, have joined classic mathematical models to enhance understanding of population dynamics, including processes of disease transmission.

Early mathematical population models have also provided the groundwork for significant advances in cellular systems modeling, with direct applications to the treatment of cancer. Mathematical models of the genetics of organisms and their resulting features continue to develop, finding new applications in epidemiology. This, in turn, has motivated meta-analysis of databases of genetic sequences of different animals (and plants), which has resulted in ideas for new disease therapies. At the same time, examination of the molecular basis of the formation of new species has deepened our understanding of evolutionary relationships. Recent advances in the theory of complex systems are providing new insights into physiological systems with multiple feedbacks and interacting components (Burggren & Monticino 2005). Indeed, the list of bio-math applications is growing (as are the applicable datasets), including the analysis of complex images (e.g., the three-dimensional images of cells provided by confocal microscopes), and the interpretation of the complex folding of proteins, of data from new genetic techniques (e.g., microarrays), and of complex nerve networks in the brain.

The rich diversity of progress described above, and the promise of future advances, has led to the establishment of strong interdisciplinary programs in biomathematics and bioinformatics at a wide variety of institutions. Graduates from these programs hired into traditional mathematics and biology departments at universities are influencing departmental culture (including promotion and tenure criteria; see section 8.4). While significant challenges remain, there is a growing realization among mathematicians that not being involved in interdisciplinary work with biologists means missing out on some of the most exciting discoveries of our time.

Biologists and mathematicians cannot simply decide to work together and then do so. Productive relationships require patience and mutual awareness of fundamental differences in how disciplines approach problems. Mathematicians entering into collaboration with biologists often require a crash course in the basic biology underlying the research, and must relearn (or learn for the first time) what many undergraduate biology majors know. Patience is appreciated from biology colleagues who take for granted a certain knowledge base when interacting with colleagues. Biologists will appreciate the same patience about topics a mathematician may assume that every educated person knows—when the reality is that very few people know about (or appreciate) "nonlinear manifolds" or "isomorphism groups."

Similarly, vocabulary can be an early stumbling block. Not only may terms mean different things in different disciplines but also there are different levels of precision in how terms are used. Confusion can especially arise for words that have both common English and technical definitions. For example, the term "chaotic" is a commonly used term that nonetheless has a precise and much narrowed mathematical meaning. A biologist may be perfectly comfortable characterizing a system as chaotic based on perceived disorder; while a mathematician would argue that the system does not meet the definitional requirements, and merely has a complicated response function. It is important to calibrate vocabulary early in a collaboration to reveal common core ideas and avoid misunderstandings.

Mathematics is a persnickety discipline. Problems are approached with a level of preciseness that biologists may be unaccustomed to. Biologists thrive in a domain of uncertainty and ambiguity. Mathematicians seek to drive these properties out of their world. In the best collaborations, biologists learn to appreciate the rigor and clarity of analytical thought that mathematicians contribute and mathematicians embrace the thrill of making accurate predictions in spite of the uncertainty inherent in biological systems.

This latter point is worth expanding on. Much discussion in this chapter has focused on why and how biologists engage in interdisciplinary work with nonbiologists. A complementary question is, why would nonbiologists—in particular, mathematicians—collaborate on problems with biologists? A compelling reason is intellectual curiosity. It is refreshing to venture out of increasingly narrow disciplinary subfields to gain a substantive understanding of research questions in other fields. Collaboration can also provide rewarding opportunities to make significant contributions to problems that have importance outside of mathematics, especially to bioscience questions that have clear applicability. Consider that the very top mathematics journals typically have "impact factors" (a calculation of overall impact based on frequency with which its articles are cited) of less than 3, while some biological journals have impact factors over 20. This is not a judgment on the relative intrinsic worth of disciplines. Rather, it suggests a certain insularity of pure mathematics research and the prospect for extending reach that collaborations with biologists afford.

Effective collaboration also requires flexibility. It is often not clear going into an interdisciplinary project what mathematical tools will be needed to best address the problem. So, broad mathematical awareness is extremely valuable, as well as the willingness to learn and apply mathematics outside of one's immediate area of expertise. Interdisciplinary work thus provides mathematicians opportunities to learn new areas of science as well as occasions to apply a variety of mathematical techniques.

Of course, these very same arguments apply to biologists attempting to work with mathematicians, and each has much to offer to their colleagues across the disciplinary boundaries. Mathematicians bring an array of modeling and analysis techniques to biological projects that can make significant contributions to the increasingly quantitative field of biology. This is particularly true now in the era of "big data." The availability of extensive data sets and high-performance computing has enabled a fundamental leap in the mathematical sophistication of models applied to solve biological problems (Napoletani et al., 2014). The growing applications, data, and computing capabilities will drive new mathematical techniques and new understandings of biological systems. This is a time of incredible opportunity for mathematicians to apply their distinctive training and expertise in fields outside their discipline. It is also a critical time to evaluate how we prepare a new generation of mathematicians within undergraduate and graduate programs. There, an increasing number of innovative programs promote interdisciplinary experiences early in a mathematics major's education. This is essential in encouraging more students to obtain mathematics degrees as well as contribute to the exciting scientific advances possible only through interdisciplinary teamwork.

8.1.5 Biology and Beyond

The case studies described above show the fruits of the mergers of the biological sciences with the major disciplines of medicine, chemistry, engineering, and mathematics. But many other established interdisciplinary bioscience-based fields exist, including biogeography, bioinformatics, biophysics, biostatistics, and biotechnology. Particularly exciting developments are occurring in the interdisciplinary merger of biology and nanotechnology. For example, materials scientists intent on manufacturing machines at the molecular level are using the effective molecular recognition properties of DNA to allow this molecule to act as a template, generating novel materials with useful properties at highly controllable rates (see Priyadarshy & Shankar 2010).

Importantly, the reach of biology extends well beyond the sciences and technology into rich interdisciplinary interactions within the social sciences, arts, and humanities. For example, environmental issues have become a very active area of collaboration between humanists and biologists. Environmental problems typically involve an intricate mix of bio- or environmental science, environmental philosophy, and policy concerns. Bioethics, a related field founded in the 1960s, addresses ethical and philosophical questions that arise from advances at the intersection of biology and medicine. Political science, government, and history are interwoven with biological principles. For example, studies of peace and war are often interpreted in the context of sociobiology, and evolutionary theory has been turned toward an understanding of human conflict (for example, Vergata, 1995). Indeed, human behaviors for good or ill are often placed within a biological context, most notably using E. O. Wilson's (1975) concept of sociobiology. As computing and robotic technologies continue to evolve, the field of human computer interactions will have relevance to social behavior as well as to the investigative sciences.

Biology has, of course, long been a topic for the arts (consider Claude Monet's *Water Lily Pond* or Van Gogh's *Sunflowers*). However, biology has also depended on art in the form of medical illustration. This dependence has existed for millennia, with medical illustration likely originating in Hellenic Alexandria during the fourth century BC, and evident as mature interdisciplinary activity in the work of such famous illustrators as Leonardo Da Vinci (1452–1519) and Andreas Vesalius (1514–1564).

Biology and religion have a long and sometimes uneasy history of coexistence, most notably in recent years in debates over evolution, creationism, and intelligent design. More fruitfully, perhaps, interdisciplinary studies involving tools and conceptual frameworks from the life sciences are helping us understand the origins of social morality, cooperation, peace, and war (e.g., Bekoff 2001). Even an understanding of how religions evolved in early human populations has benefited from the application biological principles (Dow 2006).

8.2 What Are the Impediments to Interdisciplinarity in the Sciences?

Given the richness of interdisciplinary collaborations described above, why do not more mathematicians, biologists, chemists, physicists, and others step across disciplinary lines? There are myriad potential impediments—none insurmountable, but many quite formidable. Since scientists often use jargon, or have specialized knowledge that other team members lack, frequent communication is essential for all to work productively together. Thus, it can be difficult to develop a common working knowledge, or understanding of the complementary discipline's perspective, capabilities, and limitations. Scientists are most comfortable within the confines of their narrow disciplines, but much less so when venturing into unfamiliar territory. Overcoming the obstacle of a common understanding may take many frustrating discussions, much like learning to communicate in another language. Some potential interdisciplinarians lack the patience for this process.

Interdisciplinary collaborations also take time to bear results. Within academics, the tenure clock does not recognize the extra time it takes to absorb the key concepts in the secondary discipline, to develop a shared view of a problem, and then search for appropriate techniques. Consequently, it is not unusual for junior faculty to be advised by their mentors not to pursue interdisciplinary work until after tenure. All too often, however, by the time tenure has been achieved, research paths have developed into deep ruts for which there are few institutional incentives to climb out of (see Pfirman & Martin, this volume).

It is also difficult for many academic (and nonacademic) evaluators to judge the value of interdisciplinary projects. Consider, for example, the challenges to mathematicians proposing to work with biologists. Mathematics departments, like all academic departments, evaluate the research productivity of their faculty by the number of articles published in disciplinary journals and the quality of the journals in which articles are placed. Mathematics journals follow an exacting theorem-proof format. A collaboration with biologists will typically not produce a fundamental advance in mathematics (of course, sometimes this does happen, enriching both mathematics and biology). Even if it does, the theorem-proof exploration of the result would rarely find its way into a biology journal article. Traditional mathematics departments are challenged to evaluate the worth of an article that does not contain a proof, no matter how innovative or useful the application. Often, faculty members are admonished to translate the application into work that can stand on its own in a conventional mathematics journal. Thereby, the work necessary to attain evaluations similar to departmental colleagues not collaborating outside their discipline is at least doubled.

Even when scholarly work can be easily evaluated with regard to content, there may be an attached stigma (or at least lack of appreciation) for the venues in which interdisciplinary work appears. Front-line, cutting-edge interdisciplinary journals that are the "must-publish" targets for interdisciplinarians may nonetheless have low impact factors and very small circulations of a few thousand compared with the disciplinary "usual suspects" such as *Science* (with a very high impact factor and a paid circulation of more than one million). Put differently, scientists and mathematicians working in interdisciplinary areas still face the significant challenge that a paper in *Science* is typically regarded as far, far more significant than a paper in, for example, the interdisciplinary journal *Science Studies*, targeting not only scientists but also sociologists, philosophers, historians, and psychologists.

Although there are many impediments to interdisciplinarity, there are many ways to actively promote such approaches. Interdisciplinary scientists need to remain open to new ideas, commit to learning alternative approaches and, perhaps above all else, be patient with respect to their own advancement, that of their colleagues and ultimately of the project. Beyond the individuals, institutional practices need to be implemented that provide clear incentives to departments and faculty to engage in interdisciplinary research projects. This can start proactively with, for example, workshops and other educational opportunities for evaluators so that they can learn of both the promise and pitfalls of interdisciplinary research.

8.3 Conclusion

The case studies described above demonstrate the power of interdisciplinary approaches in the biological sciences, drawing on a variety of disciplines in the sciences and beyond, for generating new perspectives, approaches, hypotheses, and ideas for future experiments. Apparent also is that interdisciplinarity in the biological sciences is typically not just a single person working in an interdisciplinary area, but rather “sympathetic” disciplinarians collaborating to bring the best of their training and knowledge together in new and innovative ways. Environments such as think tanks, centers, and institutes have all proven to be highly useful for getting dissimilar types of people together to work on interdisciplinary issues in biological sciences.

Yet, interdisciplinary work in the biological sciences can be challenging. Communicating with collaborators in other disciplines requires (re)learning disciplinary-dependent concepts, adopting new vocabulary, and committing to new approaches. And collaboration can lead to disciplinary fragmentation, a particular threat in the social sciences (Balietti et al. 2015). Even when successfully completed, interdisciplinary science may not be fully appreciated by conservative or more traditionally inclined evaluators.

Notwithstanding these limitations, interdisciplinarity in the biological sciences is burgeoning, driven by a spectrum of motivations ranging from unbridled intellectual curiosity to demonstrated practical solutions to engineering and medical problems. Importantly, federal funding agencies in numerous countries are creating funding programs that specifically encourage interdisciplinary activity (e.g., the US National Science Foundation’s “INSPIRE” funding program). Clearly, in the future the biological sciences will continue to operate within an interdisciplinary cycle, spawning new subdisciplines and, in time, changing the fabric of biology itself. As stated by Thomas Kuhn (1962), we will not recognize the most fundamental paradigm shifts in science until after they have occurred.

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Mathematics and Root Interdisciplinarity

Historical Perspectives

ERIK FISHER AND DAVID BELTRAN-DEL-RIO

In the typology that distinguishes among multi-, cross-, and transdisciplinarity it is also possible to think of a field of inquiry or discipline that lies at the root of other disciplines. Mathematics—depending on how it is conceptualized—shapes and enables work in many different disciplines, from the natural and physical sciences to the social sciences and fine arts and digital humanities (Hersh 1997). It can also support knowledge integration across disciplines. Furthermore, developments in mathematics can be correlated to cultural style periods—as in the case of Kurt Gödel's (1906–1978) incompleteness theorems and postmodern theory (Thomas 1995; Neyland 2004). Mathematics can thus be thought of as a root or foundation for other disciplines both because it is directly applicable to a wide set of phenomena, practices, and developments in many other fields of learning and human endeavor and because it underlies a fundamental form of knowledge, significantly occupying four of the originally seven liberal arts.

"Mathematics," from the ancient Greek *mathemata* ("that which can be learned"), was originally broader than contemporary use implies. It encompassed all learned knowledge, not just that which can be characterized through number. In contemporary usage, however, mathematics can be defined as the study of patterns and order within structure, space, and change. It employs logical reasoning and quantitative calculation to make statements that can be shown to be true or false based on first principles or axioms and rules of inference. Mathematics can be considered "pure" and outside of the natural sciences insofar as it investigates the properties of and relationships among idealized objects. Yet insofar as the knowledge it generates approximates physical phenomena, it can aid in their conceptualization and control, and can thus be considered "applied."

Mathematics is conventionally dated prior to any clearly written historical record with practical problems, mostly involving commerce and agriculture, eventually extending into natural science and military applications. In the European tradition, pure mathematics arose much later, with Pythagoras (*c.* 569–475 BCE). However, emergence of the systematic study of natural phenomena did not historically coincide with mathematics. Aristotle (384–322 BCE) developed a phenomenological science of nature based on understanding four distinct causes of natural phenomena, with mathematics being merely included in one of his four modes of causality.

Mathematics initially played a more prominent role in ancient astronomy than in physics. In the cosmology that framed Western scientific thinking before the sixteenth century, the celestial sphere on which the moon was thought to travel defined a dividing line between heaven and Earth, with the corruptible and imperfect beneath this line, while the heavens were a realm of perfection and perfectly circular motions. Hence early astronomers, particularly Claudius Ptolemy of Alexandria (*c.* 85–165 BCE), concluded that mathematics, also being perfect, was the appropriate tool to describe heavenly motion. Ptolemy's insistence on using only perfect circles required him to employ epicycles, circles whose centers moved on the circumferences of larger circles centered nearly (but not exactly) on the position of the Earth and around which orbited each planet. Likewise, mathematics was considered by some to be largely *inappropriate* for the study of sublunar phenomena, since a perfect tool could not describe an imperfect, corruptible world. Such a view of mathematics did not prevent the application of mathematics, for instance in the mechanical arts; but it did arguably limit its application and its interdisciplinary potential.

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Galileo Galilei (1564–1642) is generally seen the first to clearly and theoretically ground the study of nature in mathematics. The Galilean revolution is often characterized as involving his acceptance of Copernican heliocentric cosmology and insistence on experimentation and empirical "proof" of physical theories. Of even more importance, however, in Galileo's application of mathematics to sublunar motions he insisted that physicists should not seek causes, as Aristotle held, but generate only mathematical descriptions of natural phenomena.

The power and limitation of Galileo's prohibition against causes can be seen in the rapid advancement of applied mathemetics in physics. The calculus, which enables a more precise description of Galileo's chief interest, motion, was independently invented 50 years later by Isaac Newton (1642–1727) and Gottfried Wilhelm von Leibniz (1646–1716). Calculus allowed physicists to model and predict natural motions with previously unknown accuracy. In a similar development, by assuming an inverse square relationship of gravitational force and then by developing and applying a geometry of limits, Newton demonstrated what Johannes Kepler (1571–1630) had only posited, namely, that planets move in elliptical orbits. In one of several disclaimers, however, Newton significantly pointed out in a 1693 letter that his mathematical work did not reveal the more philosophical "cause of gravity itself."

With calculus, Newton also succeeded in unifying formerly disparate fields of physics. Attempts to further unify or even "end" physics with a mathematical theory of everything (TOE) continue to the present. String theory is one such attempt, and as in Newton's day, new physics and new mathematics are developed simultaneously.

Calculus is the mathematics of motion and change. Since these feature so prominently in our world, it is no surprise that calculus appears in so many fields. Calculus was developed specifically to address time and change in physical and applied questions, and has proven an exceptionally powerful tool with surprisingly wide application from the physical questions it was developed to address to problems in social sciences and statistics as well as highly abstract pure mathematics. Many fields, physics especially, require a question to be expressed as a calculus problem—a set of differential equations—to be considered a question at all. It is interesting to note that the mathematics of calculus require quantities to be continuous. Any study of the natural world based on calculus assumes the same of the processes investigated. Hence calculus as a tool to study nature builds in the assumption that the physical world is made up of unbroken rather than discrete operations. This assumption is readily violated in many areas where calculus is most widely used, such as the study of fluid dynamics. The Navier-Stokes equations, which are most often used to describe fluid flow, can exhibit complex turbulent behavior at an arbitrarily small spatial scale, smaller than the scale of water molecules, for instance. Obviously, real water could not have such small scales of turbulence. Whether such continuous processes exist at all in nature is still an open question; there is no clear consensus on whether space and time are continuous.

Similar to Ptolemy's epicycles, which are a classic example of a mathematical device that predicts but cannot explain natural behavior, the calculus—and mathematics in general—may be better thought of as an approximation, rather than an explanation of many, if not all, of the phenomena it seeks to describe and predict. What counts as authoritative knowledge thus appears intimately bound up with a reconceptualization of mathematics that in turn enabled the rise of modern political and economic institutions.

Whereas Newton, like Aristotle, distinguished mathematical knowledge of nature from "causal" knowledge, Galileo, like Ptolemy, may have been more interested in a computational and predictive tool. By the time of Pierre-Simon Laplace (1749–1827), scientists widely held that the universe was

(*cont.*)

Mathematics and Root Interdisciplinarity (cont.)

akin to a gigantic deterministic clockwork machine, and began to envision an end to physics with a colossal system of differential equations that predicted every natural event.

The Galilean revolution produced still another result—the attempt to quantify or otherwise find a secure mathematical foundation for as many fields as possible. Many believe a field of study becomes truly scientific only insofar as it can be made mathematical. Due to its tremendous success in describing natural phenomena, mathematics is often thought of as a root of scientific knowledge and, by extension, of knowledge in general. This belief largely means the application of calculus, but calculus is a deterministic tool, and in many cases cannot be applied. When calculus fails, another modern form of mathematics known as probability and statistics tends to take its place.

Probability and statistics have their own specifically modern origins in specifically modern problems such as those being presented to bankers and investors in high-risk potentially high-gain shipping ventures. About the time of the development of the calculus, for instance, Blaise Pascal (1623–1662) famously proposed that one employ a statistical wager regarding the decision of whether or not to believe in the existence of God. Shortly thereafter, the nation-state also sought to develop statistical tools that could facilitate its control and manipulation of large-scale populations and the monitoring of its citizens' activities. Contemporary scholars often propose that mathematics in the form of probability and statistics be directly applied to moral contexts and questions. Economic and risk assessment methods such as cost-benefit analysis and probabilistic risk assessment have become widespread tools for public policy, and therefore moral, decision-making.

The modern notion of mathematics as a root interdiscipline has nevertheless been challenged on a number of levels. Jacob Klein (1899–1978) argued that the ancient Greek understanding of *arithmos* differs importantly from the modern understanding of "number." According to Klein, *arithmos* always means a definite number of definite things, whereas the modern "number" replaces "the real determinateness of an object with a *possibility* of making it determinate" (1992, p. 123). The symbolic characteristic of "number" is based on seemingly paradoxical assumptions about the ontological status of mathematical objects, since it identifies mind-independent "things" with a mind-dependent "concept," namely, *quantity*.

This brief historical reflection on mathematics as a root discipline suggests that the application of mathematics to other domains is partially at least a function of what mathematics is considered to be. Moreover, different conceptions of what counts as knowledge have at various times both limited and enabled the integration of mathematics within these other domains. The extensive modern employment of mathematics in describing and predicting phenomena thus, on the one hand, can be taken as evidence of the primacy of mathematics as a form of knowledge and, on the other, comes at the cost of other forms of description and ways of knowing. In this case, at least, interdisciplinary success appears to be rooted in what constitutes a discipline in the first place.

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CHAPTER 9

INTEGRATING THE SOCIAL SCIENCES

Area Studies, Quantitative Methods, and Problem-Oriented Research

CRAIG CALHOUN

Distinctions among social science disciplines are historically forged and to some extent intellectually arbitrary. Most focus on a domain of social life: Three of the oldest and most prominent reflect Western modernity's constitutive notion that economy, polity, and society are distinct spheres. Anthropology has studied the nonmodern and non-Western, with a holism shaped by the inverse notion of less differentiated societies (and an emphasis on culture often lacking in economics, political science, and sociology). History, taking the past and change as foci, also encompasses what the social sciences divide (but then reproduces the divisions internally); it is often placed among the humanities because its ostensible particularism contrasts with the social science pursuit of generalizations. Psychology is on the margin of social science not least because it focuses on biological as well as social individuals. Geography, likewise, has encompassed both the physical environment and the spatial organization of human life. But the boundaries of all these topoi are at best fuzzy. They are matters of style as much as method—characteristic patterns of attention and ways of solving problems, tastes for different forms of presentation or internal division of labor. And indeed, the idea of method cuts two ways: Does each discipline have a characteristic method as in the arts and humanities, or is a common method basic to the unification of science? And are not there methodological diversities (among others) in each of the social science disciplines?[1]

9.1 Overview

Despite the arbitrariness and ambiguity, disciplinary boundaries are jealously defended and also maintained by habit, social networks, and funding conventions. While early social

[1] A previous version of this chapter was coauthored with Diana Rhoten. She was unable to participate in its revision or to review the substantial changes made.

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science was "predisciplinary" and often nonacademic, from the late nineteenth century, academic employment became basic to social science and disciplines became integral to the organization of universities. Disciplines organized training, publication, and employment—and disciplinary departments often became containers rather than nodes in broader networks. This worried both those who wanted more effective engagement with public problems and those who wanted more unified science.

Interdisciplinary scholarship is accordingly as old as disciplines, and central to the very idea of unifying knowledge in the university. Much is simply a matter of individuals extending the reach of their knowledge.[2] But there are also projects, as researchers from two or more disciplines combine their different methods, analytical frameworks, or empirical knowledge. They may be motivated by intellectual curiosity, desire to address practical problems, or the initiatives of funders. It is important to appreciate and understand the conditions for success in such projects (Mansilla et al. 2015) and the implications of interdisciplinary work for individual careers (Rhoten & Parker 2004). Such collaborative work may change disciplines or may simply result in new knowledge incorporated eventually into the separate fields. Only occasionally does it cumulate into the formation of an interdisciplinary field (or new discipline).

The idea of interdisciplinarity received its first explicit formulation in discussions that led to the 1923 creation of the Social Science Research Council (SSRC).[3] Charles Merriam, a political science professor at the University of Chicago, helped conceive the SSRC by calling for the "closer integration of the social sciences themselves":

> The problem of social behavior is essentially one problem, and while the angles of approach may and should be different, the scientific result will be imperfect unless these points of view are at times brought together in some effective way, so that the full benefit of the multiple analysis may be realized. (Worcester 2001, p. 16)

In September 1930, the SSRC restated this view as policy:

> The Social Science Research Council is concerned with the promotion of research over the entire field of the social sciences. The Council's thinking thus far has been largely in terms of social problems which cannot be adequately analyzed through the contributions of any single discipline. It is probable that the Council's interest will continue to run strongly in the direction of these inter-discipline inquiries. (Barnett et al. 1931, p. 286)

The SSRC was influential, partly because of the engagement of leading social scientists but also and crucially because it had access to funding from major foundations and the US government. But funding was not all on the side of interdisciplinary programs. Disciplinary

[2] At least as far back as the great early twentieth-century anthropologist Ralph Linton, leading social scientists have argued that the most effective interdisciplinary relations took place inside a single skull. Versions of this quotation are in fact attributed to a variety of scholars—much in the manner of the famous remark about standing on the shoulders of giants studied by Robert Merton (1965).

[3] While the *Oxford English Dictionary* cites a 1937 article in the *Journal of Educational Sociology* as the first printing of "interdisciplinary," versions of the term had in fact appeared annually since at least 1930 in the SSRC awards listings and reports printed in the journals of various professional societies including *Journal of the American Statistical Association, American Sociological Review*, and *American Economic Review* (Sills 1986; Prewitt 2002).

departments controlled most of the resources that flowed from student enrollments. And though the government funded an enormous amount of problem-oriented research from mission-driven agencies, by the 1970s the most prestigious funding for social science was allocated on a disciplinary basis by the National Science Foundation. Disciplines also dominated in the academic structures of most other nations. Still, postwar social scientists developed two broad interdisciplinary agendas for the improvement of social science: international knowledge and quantitative research methods. Neither was narrowly problem-focused, though building better capacity to solve future problems was a rationale for funding each.

The focus of the present chapter is on these three agendas for integration of social science: (1) area studies, seeking a comprehensive understanding of concrete patterns of social life organized in terms of geopolitical regions and/or civilizations; (2) quantitative and mathematical research methods, shared across disciplines to provide tools to support innovation and greater rigor inside different disciplines; and (3) problem-oriented research, bringing together different disciplinary perspectives and tools to address issues of public concern.

Although all three have older roots, in the United States they were given strong momentum by the mobilization of social scientists in the context of the New Deal and World War II. After the war, researchers returned to universities both invigorated by their wartime experiences and challenged by a sense of their own previous limits. They sought widespread improvements in social science in order to make it an effective source of objective knowledge that could inform government policy. Immigrants educated in Europe added knowledge and intellectual perspective. At the same time, former soldiers swelled university enrollments to record numbers and social science departments grew. And the US example became globally influential in an era of US academic (and other) dominance.

9.2 Area Studies

The emerging Cold War and nuclear arms race added to anxieties over peace and global influence. The SSRC founded a Committee on World Area Research in 1946. In 1950 the Ford Foundation began the Foreign Area Fellowship Program, which it later turned over to the joint SSRC–American Council of Learned Societies (ACLS) committees on different world areas to administer. Ford put nearly 300 million dollars into this project, and in due course was joined by other foundations and by the US government, which made large investments in foreign area research and language teaching. These supported university centers focused on different world regions. These were usually not allowed to make their own independent faculty appointments; that was reserved to disciplinary departments. But initially they had funds to attract and support the research of disciplinary academics.

The dominant paradigm of area studies was distinctively American, and responded to a widespread sense that the country lacked the knowledge of other world regions needed to support the world leadership the United States was assuming. But the growing interdisciplinary fields built on traditions of European scholarship. Islamic, Indic, and Chinese civilizations had been the object of "orientalism," with brilliant examples from Germany; colonial administration had shaped the creation of institutions like Britain's School of Oriental and African Studies. In the United States, the area studies architecture was distinctively synoptic, dividing the whole world into regions. Overall, they mirrored US military and diplomatic organization (Cummings 1997). However, practical purposes were in the background; they explained the investment but not the organization.

Area studies fields differed in the extent to which research and teaching focused on contemporary politics, civilizational history, or economic development and thus the prominence of different disciplines— and of the humanities alongside social sciences. The Cold War put politics at the center of Russian and East European studies, and even contributed to the demarcation of the region itself. South Asian studies certainly confronted political issues, but focused more on civilization and culture. Economic development was front and center for Latin American studies, and the formation of "new nations" was a key theme for African studies.

During the postwar period, however, all the area studies fields shared a broad intellectual orientation associated with the idea of modernization. Economic development, political reform and the creation of new national institutions, social transformation, expansion of literacy and consequent cultural production, and even change in psychological attitudes were all seen as parts of a common process. And if modernization described what was shared in this process, different histories and cultures shaped distinctive patterns in each region. This encouraged a two-way trade in which area knowledge was fitted into and completed the disciplinary analytic frameworks (sometimes modifying previous generalizations) while the disciplinary frameworks gave structure to area knowledge. Language study and contextual knowledge could be seen as tools for such research.

The connection and complementarity modernization theory facilitated between area studies and social science disciplines came unstuck in the 1970s. This reflected the end of the great decolonization era, collapse of faith in economic development, and crisis in modernization theory – especially when faced with Marxist critiques. But a long-standing epistemological fault line also contributed. As quantitative methods and the pursuit of universal laws became increasingly dominant in sociology, political science, and especially economics, simultaneous membership in area studies fields came to be seen as a matter of divided loyalty. Disciplinary knowledge was understood as ideally abstracting from specific cases and contexts to establish more universal laws. The area studies fields, by contrast, seemed to be particularizing, focused on the specifics of local conjunctures of history, culture, politics, and even environment.

This was always a caricature of area studies research, and perhaps a misunderstanding of what disciplines themselves achieved. It is easy to mock either side: The psychologist who thought human nature could be found in experiments involving only white, middle class, male American undergraduates; the anthropologist who responded to every assertion of a more general causal pattern with "well, that's not so on the island I studied." But there is a point of more basic significance.

The area studies projects at their best were not so much about idiographic particulars as about the notion that there were and are different ways to be human, to be social, to be political, and even to have markets—and therefore that the pursuit of more general knowledge required attention to specific historical and cultural contexts and patterns. Such knowledge could be of broad application without being abstractly universal. And indeed, the area studies fields contributed to major analytic perspectives that far transcended their initial sites of development. Benedict Anderson's (1991) account of nationalism as a matter of imagined communities was informed by Southeast Asian studies, but not contained by it. So was James Scott's (1998) effort to understand the ways states viewed societies. Dependency theory developed as an effort to understand specifically Latin American problems, as did Albert Hirschman's work on development assistance and unbalanced growth (Prebisch 1950; Hirschman 1958; Frank 1967; Cardoso & Faletto 1979). The "world systems theory" of Immanuel Wallerstein was deeply shaped by African studies as well as by Braudelian global history, Marxist political economy and indeed the earlier Latin American dependency theories (Wallerstein 1974). And so forth.

Each of these examples became part of active interdisciplinary discussions—of development and underdevelopment, class and power, power and knowledge, states and nations. Of these, only development studies really became an academic field of its own—more substantially institutionalized in Britain and some other countries than the US (though rural sociology which once focused mainly on the United States became increasingly part of global development studies). Marxism was for a time a vital interdisciplinary discussion, with strong social movement links, but never with strong academic institutionalization outside the communist countries. Interdisciplinary political economy flourished from the 1960s to 1980s, often integrated with comparative historical research, but this receded.

This points to a more general problem for interdisciplinary work. When it lacks institutional conditions of reproduction, it is at the mercy of disciplines that may claim it, ignore it, or incorporate some ideas from interdisciplinary projects without providing ways of sustaining the intellectual conditions that produced them. While a few universities set up autonomous departments of Latin American or East Asian studies, many more set up interdisciplinary committees or centers and left the appointment and promotion of faculty and the awarding of PhD degrees to disciplinary departments.

In the 1950s and 1960s, the area studies fields were relatively well financed and often able to offer funding to students from various disciplinary departments. In the United States, the Peace Corps brought a new infusion of students—once again like the soldiers with motivating life experiences—but this time also often with language skills and local knowledge. More generally, while the university system expanded, there were jobs for the political scientists and sociologists with area studies emphases. This changed with the mid-1970s recession. Academia stopped expanding and suffered a shortage of faculty jobs, sharp tightening of tenure standards, and new pressures on graduate students to demonstrate disciplinary publications before entering the job market. In this context, disciplinary departments exercised discipline by rewarding intradisciplinary achievement and limiting credit for interdisciplinary work. At the same time, area studies programs saw their proportionate funding decline, not least as graduate student financial aid became widely tied to teaching assistantships administered by departments. By the 1980s and 1990s, efforts to shrink PhD cohorts further consolidated disciplinary control.

Economics effectively seceded from area studies as it relied increasingly on mathematical models and on theories that stressed more or less universal microfoundations. Economists who retained strong area interests often wound up in interdisciplinary programs rather than economics departments—not just area studies but also urban studies, policy analysis, and development studies—or working for the World Bank or other nonacademic institutions. In varying degrees sociology and political science followed suit, leaving the area studies fields increasingly tilted toward the humanities.

From the 1970s and especially after the end of the Cold War, many economists and social scientists began to conceptualize globalization as a universalization that would eliminate the need to know about national or regional contexts. The "end of history" was operationalized as the universality of markets and media. Ironically, in other words, attention to globalization came to a considerable extent at the expense of attention to the specific regional and other contexts through which globalization was refracted and in which it took on different meanings.

It would be an error, nonetheless, to write the obituary of area studies programs or context-specific social science. In the first place, formal, universalizing approaches have their limits. Take the recent struggle of experts in international relations to develop stronger approaches to religion when it unexpectedly loomed much larger in the real world than predicted by the resolutely secular academic literature of their field (Hurd 2007). The difficulties have to do with reigning theories, of course, but also with institutional and intellectual distance from those with more knowledge—often area studies specialists and researchers from the humanities and fields like history and anthropology that straddle humanities and social science.

Secondly, area studies are being creatively reimagined. Important new engagements take up connections between regions—for example as Islam or Pentecostalism flourish in different regions, or as trade, culture, and diplomacy are recognized to follow the Silk Road or pan-Asian coastal trading routes.

Third, with shifts in global economic growth and the end of the Cold War, many areas previously lumped together as "underdeveloped" are taking on new geopolitical importance. Globalization itself has helped produce new patterns of regional power and association.

Fourth, the very globalization of higher education creates new demands for regional knowledge and regional centers to mediate the international relations of universities. This includes the flow of students with interests in their native regions. It extends to preparing students of all origins for careers that connect them increasingly to other regions. It is also a matter of research. This has been reshaped both by increased transnational scholarly collaboration, by the migration of many scholars from other regions to work in Western universities (while still studying their home regions), and by growing sophistication among social scientists in previously underdeveloped regions. Area studies centers have often morphed into portals to manage these diverse connections. International funding plays no small role.

9.3 Quantitative and Formal Methods

Like area studies, quantification and mathematical formalization had long histories in social science but received renewed emphasis from wartime engagements. The war shaped the rise of modern computing, the development of large datasets, and strategic thinking that contributed to game theory.

Statistics had long been important to social science, both in the sense of technique and in that of an accumulated knowledge base. Statistics figured as one of the founding disciplines in the SSRC and one of the first brought into the London School of Economics and Political Science (LSE). The rise of testing in psychology (and related interdisciplinary education research) was prominent, spurred on by its use in military efforts to classify recruits as well as by the expansion of public schooling. In both criminology and public health, efforts to introduce treatments and measure changes in rates became basic. If the state was a central collector and user of statistics (as the name suggests), the pioneers of social science recurrently mobilized statistics to make cases for social reform (Stigler 1986; Porter 1995). Both policy makers and advocates wanted to know "the statistics" on crime or employment.

At first this meant overwhelmingly descriptive statistics. Statistics grounded in probability theory made uneven headway in the social sciences before World War II (Hacking 1990). They mattered most in economics and psychology, though even there much work continued to focus on absolute numbers, percentages, and measures of association. The problem of establishing patterns of heredity was influential in development of multivariate approaches, inspiring figures such as Galton, Edgeworth, and Pearson. As both Pearson and Yule analyzed families of curves, this work moved out of evolutionary theory and into economics and social policy. Analytic efforts to compare groups, to track interventions, and to understand differential rates of occurrence grew increasingly influential.

Although many of the specific techniques used in social science have much older provenance, their use became widespread only in the 1960s and after (Raftery 2005). Both multivariate data analysis and mathematical modeling were, for one thing, greatly aided by greater computational power and easier access to it. Graduate training programs substantially increased the numbers of social scientists able to use sophisticated quantitative methods. Statistics departments remained prominent, though increasingly dominated by biostatistics. Social science was transformed as quantitative research methods spread through most disciplines. This was not just from statistics departments outward. Many of the specific research techniques taken up by the early "behavioralists" in political science, for example, came from sociology and social psychology.

This flow of knowledge was supported by interdisciplinary centers devoted to quantitative research.[4] Above all, they were associated with the rise of survey research— in what one of its leaders described as the "golden era" of a kind of interdisciplinary social psychology (Sewell 1989). This had early roots outside academic social science and was aided by the appeal of some of its results to journalists. Accounts of "the average American" joined statistics on a variety of "deviations" (Igo 2007). Opinion polls informed not only political campaigns but also market research. Academic survey research developed as an interdisciplinary field dedicated to raising the standards of this partly extra-academic pursuit at the same time as advancing social science.

Survey research became central to an interdisciplinary field of specialists in data collection, closely related to but somewhat distinct from statisticians as specialists in data analysis. Survey research centers became institutional bases and meeting points for methodologists and quantitative researchers from different disciplines. Survey data informed (and transformed) the study of elections, inequality, race, education, and other topics. In some cases, a large, complicated dataset—like the Panel Study of Income Dynamics (PSID) begun in 1968—developed its own cadre of experts and became the focus of interdisciplinary discussion. In other cases, a survey program was not topically specific but opened an integrated data collection effort to researchers from different fields. Thus the National Opinion

[4] With money from the Rockefeller Foundation, even before the war the SSRC funded the creation (and even the physical buildings) of institutes for social science research at universities such as Chicago and North Carolina. The Rockefeller goal was always concrete, "realistic" solutions to pressing social problems. Realism was identified with quantification—and also with short-term politically palatable solutions, though on the later count Rockefeller was often disappointed (Richardson & Fisher 1999; Camic 2007).

Research Center's (NORC) General Social Survey has since 1972 provided researchers from different disciplines the opportunity to purchase questions or modules to gain data on their specific concern that could be related to a common background of demographic and attitudinal data.

Survey data remain important to social science, but survey data collection is now a technical skill organized largely on nonacademic bases. Surveys are conducted by specialized organizations on a contract basis. Some of these are based at universities and some are for-profit companies. Most social scientists who analyze survey data today have no experience collecting it (as did their predecessors a generation earlier). There is major work to be done on data archiving and accessibility, but in itself this is not social science.

Methodological excitement is now focused more on "data analytics" that can be deployed on a variety of preexisting data sources. With the rise of computerization, a host of different transactions result in large datasets. Records are kept of purchases, doctor's visits, insurance, locations tracked by GPS systems, e-mail metadata, and so forth. Search algorithms facilitate data mining; machine learning helps them get "smarter." Often called "big data" because millions of cases may be involved, it is perhaps more relevant to say these data arise as by-products of transactions, relatively disorganized or structured for purposes different from research. There are exciting possibilities for using such data, though also obstacles, including notably the fact that many are kept from researchers' use for proprietorial or data security reasons.

Big data suggests not only a renewal of interdisciplinary engagement among quantitatively inclined social scientists but also potential for a rapprochement between modelers and empiricists. The two were joined in the cybernetics of the 1950s and the systems theory that grew from it but often diverged later. In economics, the "microrevolution" of the 1970s put mathematics in the ascendant. Game theory, agent-based modeling, and similar approaches were often pursued in the abstract rather than with meaningful real-world data. This was true even for econometric and statistical data, but the gulf was wider where empirical knowledge was based on ethnography or comparative historical research. The improvement of formal techniques and the distance from other forms of knowledge spread into political science and, to a lesser extent, sociology.

But the trend may be to close the gap. Empirical (applied) economics has enjoyed a recent resurgence. Improved data and improved computing power helps. Behavioral and other experimental research is also prominent. This is perhaps more "cutting edge" in economics than psychology, where the dominant interdisciplinary connections extend to the brain sciences and the study of cognition. Network analysis is another interesting case, spreading from mathematics (especially graph theory) and anthropology to achieve a center of gravity in sociology and influence work throughout the social sciences. Formal analysis of complex systems was pioneered in the natural and physical sciences but has diffused into social science through interdisciplinary centers like the Santa Fe Institute. In each case, there is potential for renewed mutual engagement between formal modeling and empirical analysis.

Waves of innovation in research methods are commonly greeted by dramatic declarations of revolutionary leaps forward and capacity to integrate all of the social sciences (or to integrate social science fully into science generally). They do create bases for interdisciplinary collaboration, especially where shared support facilities like survey research centers are important. But for the most part, new tools sustain interdisciplinary fields only temporarily.

Research based on different tools is incorporated into individual disciplines and interdisciplinary fields defined by topics and problems.

9.4 Problem-Oriented Research

Both area studies and quantitative methods flourished partly on the basis of expectations that they would contribute to practical problem-solving as well as more rigorous academic knowledge. Both did. Quantitative research methods diffused into policy research both at universities and in government agencies and think tanks. Context-specific international knowledge was important to diplomacy, foreign policy, and practical development work. For the most part, though, the social sciences retained an emphasis on "pure" scholarship distinct from more "applied" research. Within universities, the growth of professional schools provided an alternative site for problem-oriented work.

Recently, both foundations and governments have voiced disappointment in the limits of social science contributions to solving public problems. This echoes calls for relevance in the 1960s. One difference is that today funders more often bypass academics to seek research from think tanks. Universities risk losing some of their centrality to the contemporary knowledge ecology if they do not remain central to problem-oriented research—and many universities have responded by launching cross-disciplinary initiatives to help tackle major problems like climate change, urbanization, or poverty eradication. The other difference is the proportionately much larger role of professional schools today than 50 years ago. Both are challenges for social science. An important response has been more emphasis on interdisciplinary, problem-oriented research.

In fact, social science—both disciplinary and interdisciplinary—deserves more credit for producing useful knowledge than it has received. But social science disciplines have often resisted putting problem-oriented research front and center. Part of the reason for this is emphasis not just on purely academic research but also on discipline-specific research agendas. As Pierre Bourdieu (1988) argued, academic fields value what they regard as distinctive and essential to them; transactions at their margins may be required to secure resources but they are commonly denigrated—as "pure" artists may denigrate mere illustrators or designers. So each discipline values both that which is interior to it and that which is more pure or fundamental. This hierarchy imposes distinctions and divisions where research might better be served by collaboration and communication. Whether the issue is risks to the global financial system or the growth of megacities, effective problem-oriented research calls for the combination of different intellectual tools and perspectives as well as different disciplines.

The problem here is not just the prestige hierarchy; it is also the very notion that pure science always precedes application in a one-directional linear process. In fact, the relationship may be much messier and more iterative; application may also be experiment, and the observation of poorly informed practical action may be the basis for better knowledge. This often involves a process of cocreation in which nonacademics are linked into the knowledge-producing networks and processes. The nonacademics may be researchers working in other, more practically oriented settings. They may be "practitioners" who bring knowledge from their experience. They may be officers of organizations that control relevant data. Among their contributions may be to help academic researchers ask better questions, so it is important that they be engaged earlier in the planning of research.[5] Social science has relatively underdeveloped networks of communication and collaboration both among researchers pursuing different kinds of studies and with practical actors.

Claiming value freedom and resisting external control, disciplinary social science often minimizes the development of relationships with relevant practical actors. But these are important, including at the fundamental point of problem choice (Calhoun 2008). While science may require freedom from efforts to interfere with results, it need not be altogether autonomous about agendas. More appreciation is needed of how much intellectually fundamental work is produced in efforts to understand and address practical problems and public issues. Donald Stokes (1997) termed this research "in Pasteur's quadrant" after the way microbiology was pioneered by efforts to stabilize beer production. Examples abound in social science.[6] Many of the most important are products of interdisciplinary fields and projects defined by their efforts to address public problems and inform public debate.

The interdisciplinary character of problem-oriented social science is often limited to a form of parallel play. Economists and sociologists both study inequality and mobility for example. Their work often follows distinct paths; occasionally a researcher makes a point of connecting them (e.g., Piketty 2014). Such work addresses a common domain of public interest, but is not necessarily joined in collaboration on specific problems.

But problem-oriented research can be much more effectively organized and explicitly interdisciplinary. This can be relatively short-term. For example, the sense that welfare reform was urgent mobilized many researchers (and funders) in the 1990s. Likewise, funders today have committed significant resources to studies of obesity and potential societal responses and seek to mobilize social and behavioral as well as biomedical scientists. Climate change is generating a similar mobilization, as it is recognized that the demonstration of its existence and causal dynamics by natural and physical scientists needs to be complemented by economics and other social science in order to generate practical solutions—say in the development and pricing of carbon options.

But short-term, problem-driven interventions can also shape long-term scientific agendas. Take demography. Family planning and censuses had long histories, mostly outside academia. In the early twentieth century, a connection was spurred by anxieties over potential for a sort of negative evolution and calls for eugenics. By the 1950s and 1960s, family planning was linked to concerns for economic development, population growth, and the role of women. The Rockefeller and Ford Foundations played key roles in funding academic research centers, data collection, and organizations like the Population Council. While the research did contribute practically useful knowledge, it also shaped basic understandings of social structure. Population studies today may not be quite as free of concerns for family planning or overpopulation as microbiology is free of focus on brewing, but problem-oriented research has clearly shaped a field of knowledge not limited to the initial problems.

[5] Changing contexts and networks for knowledge production have been a theme in science studies. See, among many, Nowotny et al. (2001).

[6] To cite a single example, Robert K. Merton and Paul F. Lazarsfeld are known respectively as a leading social theorist and methodologist of the postwar era. Yet most of their extraordinarily influential research (and much of their training of graduate students) was financed through grants for problem-oriented research to Columbia's Bureau of Applied Social Research.

A fourth kind of problem-oriented interdisciplinary field focuses on the education and support of professionals who use the contributions of different disciplines in their work. This is sometimes left out of accounts of interdisciplinary social science, but in fact professional schools are major sites of interdisciplinary collaboration in research as well as teaching. Schools of business and management, social work, public policy, and international affairs are among the most important sites of interdisciplinary social science. Schools of law, nursing, medicine, and journalism all employ social scientists and provide interdisciplinary bases for their work. In each case, the focus is on integrating tools and perspectives from different social sciences into the problem-solving capacities of professionals.

Funding has often been a crucial stimulus to problem-oriented social science, though links to social movements have also been influential. It may be particularly important to all social science in the future. Funding for basic research awarded on the basis of disciplinary evaluations (as through National Science Foundation procedures in the United States and older research council procedures elsewhere) is a small and declining proportion of total funding. Indirect funding for research based on revenues associated with student enrollments is under pressure. Philanthropic donations are an important growth area, but they too are commonly focused on areas of expected practical contribution. This places a premium on the capacity of social scientists to integrate problem-oriented research into the production of more fundamental knowledge.

9.5 Conclusion

Interdisciplinary fields form as researchers take up themes or issues that either do not fit the classificatory scheme of disciplines or need attention from several. This may be driven by social change, as for example the combination of World War II, the Cold War, and growing globalization shaped the rise of area studies. Pressing public issues, like environmental degradation and climate change, may stimulate problem-oriented interdisciplinary research. New tools can also be important, as quantitative and mathematical research methods not only diffused across the social sciences but also created an interdisciplinary field of experts in methodology. But for a new field to reach critical mass and endure depends not just on intellectual interest but also generally on funding and potential for impact. All three of the kinds of interdisciplinary research just mentioned have benefited from the support of foundations and government agencies and from the interest of policy makers (and sometimes broader publics) in the products of research.

Institutional support inside universities is also influential. So powerful is the model of disciplinary departments that there is a tendency to impose it even on fields that initially embraced interdisciplinarity. For example, the study of media and communications has grown as a new focus at the interface of several disciplines. Yet as it became one of the fastest growing of social science fields, and secured a funding basis by proliferation of successful degree programs, it commonly adopted a departmental organization and calls proliferated to make it a discipline, reinforced by a growing practice of recruiting faculty members from the graduates of PhD programs in communications rather than one of the older disciplines (Calhoun 2011).

The focus in this paper has been on fields that have stayed interdisciplinary and not departmentalized. These have relied on two main organizational structures. First, professional schools bring together faculties educated in different disciplines but united by a mission to train nonacademic specialists in fields of practice. Some, like law, have roots in old, even premodern disciplines. Others, like business, public policy and now, indeed, communications, are formed from interdisciplinary collaboration. Of course, like new disciplines, they may gradually take over the training of their own new members and reduce ties to their original disciplines. Second, interdisciplinary centers or institutes offer support and linkages to researchers from different disciplinary departments, but commonly lack the capacity to appoint their own faculty or give their own PhD degrees. This is partly precisely to prevent them from turning into new disciplines themselves.

Area studies flourished for decades after World War II as quasi-autonomous interdisciplinary fields. Supported usually by centers that complemented disciplines, they also had close links to schools of international affairs and diplomacy. The interdisciplinary context they provided nurtured widely influential intellectual perspectives as well as work highly specialized in its context. They went through a period of crisis after the end of the Cold War, with weakened connections to disciplinary social science, but are enjoying renewed prominence as mediators of international academic relations. At their best, they helped produce very mobilized and different disciplinary perspectives in order to achieve an inclusive, integrated view of societies or cultures in different settings.

Bringing more sophisticated quantitative tools to social science was a major interdisciplinary initiative of the postwar era. Largely successful in the United States and some other countries, and more in some disciplines (like economics) than others, the interdisciplinary initiative has been renewed with successive advances in methods. Quantitative research methodology generally does not pose any particular topic or focus for investigation. But specific tools do sometimes carry intellectual perspectives, as for example survey research lends itself to the idea of discrete individual respondents or network analysis emphasizes relationships. Overall, quantitative approaches have been linked to abstracting particular aspects of social life from their contexts. This has encouraged an unfortunate divide between knowledge produced through qualitative and quantitative research. Researchers focused on contexts have often been resistant to formalization of their knowledge to aid in comparison and generalization, and researchers focused on formalization have often been willing to dispense with learning what context-specific knowledge can offer.

The social sciences have retained substantially the same disciplinary structure since their formation in the late nineteenth and early twentieth centuries. Interdisciplinary scholarship has brought new knowledge and intellectual innovations but not changed the overall structure. Abbott sees this as likely to continue, because the disciplines control much of the allocation of academic resources and capacity to reproduce (Abbott 2001). Others see the disciplinary system as brittle and more likely to decay or be transformed (Fuller 1991; Turner 2000). There have been periods of much greater interdisciplinary cooperation and periods of relative retrenchment, and there have been important shared agendas like "institutionalism" or comparative historical studies of social change (Hall 2007). There have been numerous calls for the reorganization of social science, such as Wallerstein's (2003) suggestion that there be a regrouping around quantitative, ethnographic, and historical methods. But social science disciplines have shown great capacity to retain their identity and mainly "topical" organization even while changing their content. Even where intellectually innovative, they are institutionally conservative. It may be that only massive changes in universities themselves (not impossible as pressures grow) would fundamentally change the disciplinary-departmental order. If disciplinary departments dominate one-sidedly inside universities this could, ironically, increase the extent to which funders and policy makers turn to other sources for usable knowledge—especially of the sort that problem-oriented research could provide.

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CHAPTER 10

INTERDISCIPLINARY ARTS

TANYA AUGSBURG

The interdisciplinary arts have yet to receive their fair share of attention within the existing literature on interdisciplinarity even as interrelations between the arts have become increasingly commonplace. As David Cecchetto et al. point out, "previous research on interdisciplinarity between the arts has been strangely piecemeal, especially when one considers the abundance of recent scholarly writing devoted to the challenges and possibilities of academic interdisciplinarity" (Cecchetto et al. 2008, p. xii). To note one prominent example, Julie Thompson Klein's seminal 1990 study *Interdisciplinarity* includes bibliographies for the social sciences, the humanities, and the sciences—but none for the arts. The tendency among scholars whose expertise lies outside the arts to conflate the study of art history or the study of musicology with the study of interdisciplinary arts has perhaps contributed to this relative lack of attention—again within the literature on interdisciplinarity, which has traditionally focused more on the social sciences, and, to a somewhat lesser extent, the sciences and the humanities.

Complicating matters has been the lack of consensus about what the interdisciplinary arts entail, which is not surprising given ongoing debates about the arts in general. Authoritative definitions for the interdisciplinary arts written by interdisciplinary artists and scholars are difficult to find. As historians of multimedia Randall Packer and Ken Jordan concede, "definitions are confining" (Packer & Jordan 2001, p. xxxiii). Artists who value artistic freedom and originality have been known to resist participating in normative discourses that definitions often serve to establish. Tactics of resistance can include downright refusals but they can also entail deferrals from answering the question, "What are the interdisciplinary arts?" by highlighting the lack of canonical definitions—which happens to be the approach Eckerd College's long-standing interdisciplinary arts program takes on its website: "Look in any arts or cultural history text and you'll not likely find an entry for *Interdisciplinary Arts*" (http://www.eckerd.edu/academics/interdisciplinaryarts/about/index.php).

10.1 Interrelations

Just because definitions are scarce or not yet authoritative does not mean they do not exist. Two well-crafted definitions are worth noting here: the first within the interdisciplinary

Augsburg, T., *Interdisciplinary Arts.* In: *The Oxford Handbook of Interdisciplinarity, Second Edition.* Edited by Robert Frodeman, Julie Thompson Klein, and Roberto C. S. Pacheco: Oxford University Press (2017). DOI 10.1093/oxfordhb/9780198733522.013.12

studies (IDS) literature, and the second, apparently influenced by it. Within the IDS literature, James W. Davis offers the following definition in his history of the well-regarded albeit eventually ill-fated interdisciplinary arts program at San Francisco State: " 'Interdisciplinary arts' . . . came to be defined as original, creative works that synthesized theory and practice (ideas and applications), and that also integrated two or more elements of expression (choosing from sound, images, movement, text, and spatial/temporal modes of expression)" (Davis 2009, p. 103). Alternatively, the interdisciplinary arts program at Arizona State West defined the interdisciplinary arts on its former website as a course of study: "Interdisciplinary arts means an approach to study and training in the arts, performance and creativity that focuses on how multiple artistic disciplines combine in an integrated way with an emphasis on new concepts and experiences and artistic way of working." Both definitions emphasize integration not only of art forms, disciplines, mediums, or media but also the synthesis of ideas and artistic practice in the study and production of interdisciplinary artworks. More specifically, both definitions suggest that the interdisciplinary arts involve more than the synthesis and integration of art media, mediums, and disciplines. In other words, the interdisciplinary arts are reflective of, and characterized by, their interrelations with academic disciplines, fields, and discourses within and outside the realm of art. At their core the interdisciplinary arts exemplify what has been termed as either a wide or broad form of interdisciplinarity (Newell 1998; Klein & Parncutt 2010).

Their broadness suggests additional qualities. Broad interdisciplinarity connotes inclusivity, another integral feature of the interdisciplinary arts. Inclusivity in turn implies openness to continuous change and innovation. Outwardly and continually inclusive, expanding, evolving, and innovative, the interdisciplinary arts defy attempts at not only definition but also periodization, categorization, comparisons, theorization, and typologies—in other words, the established arsenal of concepts, methodologies, and approaches that scholars have deployed to study and understand the arts (Klein 2005, pp. 108–109). Rather than aim for the definitive, scholars interested in studying and researching the interdisciplinary arts would do well to accept from the onset that they will never have the last word on the subject.

The rest of this chapter offers a brief and necessarily incomplete overview of what has been written on the interdisciplinary arts within academic scholarship on the creative arts. The comprehensive and authoritative history of interdisciplinarity within all of the arts across cultures has yet to be written, and space limitations prohibit any attempt here. Instead, this chapter is offered as an initial overview on which subsequent research on interdisciplinarity in general, and the interdisciplinary arts in particular, can build. My outline draws from an extensive review on the existing literature on interdisciplinary arts, which has focused its attention on a few established traditions within the creative arts literature while ignoring many other important strands of interdisciplinary arts such as my own areas of specialty, performance art and feminist art. This chapter does not include a discussion of interarts research within art history and musicology, as Klein has offered such accounts elsewhere (Klein 2005; Klein & Parncutt 2010).

From my research, I have identified five major integrative aspects highlighted in the existing literature on the interdisciplinary arts: (1) the Wagnerian *Gesamtkunstwerk*, the perceived fusion between the arts, that is, the "unified" or "total work of art"; (2) the legacy of the historical avant-garde, with its focus on radical juxtaposition; (3) the continuation of post–World War II arts experimentation in between and among multiple art mediums simultaneously with Happenings, intermedia, and multimedia; (4) the intersections between art, science, and/or technology, particularly that which is known as electronic or digital arts since the rapid developments in computers, communications technology, biotech, and new media; and (5) interdisciplinary arts as its own emergent subject of inquiry, practice, and research that encompasses the previous four aspects as well as a rhetoric of its own.

10.2 Richard Wagner's *Gesamtkunstwerk*: The Quest for Unity and the Total Work of Art

Interdisciplinarity is often viewed as dependent on, and a response to, the concept of disciplinarity. The concept of the interdisciplinary arts is not only a reaction to the division of art mediums—it also counters the valorization of the "purity" and "autonomy" of each art medium by modern and modernist aesthetics since the late eighteenth century. Writing in 1920s, the philosopher Walter Benjamin observed that the impulse toward unifying the arts was evident as far back as the seventeenth century, while in the nineteenth century Friedrich Wilhelm Joseph Schelling and Richard Wagner traced back interrelations between the arts all the way back to Ancient Greek drama (Koss 2010). Nonetheless, as the art historian Juliet Koss points out in her monumental study on Wagner's influence on modernism,

> within the discipline of art history . . . scholars regularly invoke the *Gesamtkunstwerk* as a countermodel for the "advanced art" of European modernism, conveniently erasing the concept's revolutionary origins. . . . Such assessments invariably oppose the *Gesamtkunstwerk* to such basic principles as artistic purity, autonomy, and medium specificity (the idea that each art work should develop and present those attributes specific to medium). (Koss 2010, pp. xi–xii)

Many existing theoretical considerations and historical accounts of the interdisciplinary arts begin with Wagner's oft-misunderstood concept of *Gesamtkunstwerk*, which contained elements of complete integration or fusion while still respecting each medium's autonomy. Neither the term *Gesamtkunstwerk* nor the dream of total unity, however, originates with Wagner. The term has been traced back to an 1827 text of philosopher Karl Friedrich Eusebius Trahndorff (Koss 2010). Koss points to a 1803 lecture by Schelling, in which he simultaneously exalted ancient Greek tragedy's unification of art forms while expressing a hope for future synthetic form of opera, as laying the groundwork for Wagner's later ideas (Koss 2010, p. 11). In two essays, *Art and Revolution* and *The Art-Work of the Future*, Wagner envisioned a total artwork that would unify and synthesize poetry, music, and dance in order to create an "integrated drama," "the consummate artwork of the future." Nevertheless Wagner's concept of the *Gesamtkunstwerk* was paradoxical, as it unified multiple art forms while keeping their individual distinctness and independence as they contributed to its creation. In other words, it suggests both unity and autonomy. So the term *Gesamtkunstwerk* in itself is an integrated term, containing elements of what in the literature on interdisciplinarity considers both multidisciplinarity and interdisciplinarity.

In Wagnerian opera, much more that art forms were unified. The theater was designed to give audiences a total immersive experience, which, as Koss points out, "often stands for an artistic environment or performance in which spectators are expertly maneuvered into dumbfounded passivity by a sinister and powerful force" (Koss 2010, p. xii). The orchestra pit was lowered to become hidden, and elaborate sets masked intricate mechanics. Wagner's ideas for his Festival Theater additionally blurred the traditional distinctions between audience and stage.

Moreover, the *Gesamtkunstwerk* attempted to go beyond the aesthetic realm to unite with nationalistic and political aims. While Wagner may have envisioned a new Athens, the philosopher Theodor Adorno would subsequently link it with anti-Semitism and German fascism of the 1930s (Adorno 2005; Koss 2010, p. 279). Wagner's antimodern and anticosmopolitan stances, which ultimately resulted in his decision to locate his Festival Theater in the small town of Bayreuth, nonetheless set the stage for revolutionary innovation within the arts beginning with the historical avant-garde during the first three decades of the twentieth century.

10.3 The Historical Avant-Garde and Radical Juxtapositions

The close associations of interdisciplinary arts with new and experimental art developments harken back to the tradition of the historical avant-garde movements (Futurism, Dadaism, Constructivism, and Surrealism). The invention of new art forms such as collage, concrete poetry, sound poetry, performance art, montage, photomontage, assemblages, constructions, readymades, mobiles, and kinetic sculptures was grounded in artistic innovation, revolutionary aspirations, and a sense of the new. They were also foundationally integrative as the avant-garde combined established art genres and incorporated materials not previously included in, or considered as, art or art media.

For example, Georges Braque and Pablo Picasso in 1912 invented collage—the integration of paint on two-dimensional planes with nonpaint such as newspaper fragments in painting that would later extend to three dimensions with their cubist constructions and Kurt Schwitters's assemblages. The Italian Futurist composer Luigi Russolo made the case for composers to consider the noises of modern life for the renewal of music in his 1913 manifesto *The Art of Noise*. Marcel Duchamp laid the groundwork for both conceptual art and kinetic art when he created his first readymade *Bicycle Wheel* (1913) by attaching a bicycle wheel to a stool. When several years later in 1917 Duchamp signed the fictive name R. Mutt on a urinal, he challenged philosophically the limits of art by calling into question both the originality and status of the art object.

The Dadaist Hugo Ball is often credited with launching performance art when he recited noise poetry at the Café Voltaire in Switzerland in 1916. The Russian Constructivist Arseny Avraamov in 1922 composed and organized *The Symphony of Sirens*, an outdoor public event performed by thousands of musicians and workers, incorporating synthetically modern sounds such as cannon shots, foghorns, and factory sirens into his musical score. In 1924, Sergei Eisenstein created a novel way to forge continuities and overlaps within different strips of film with his editing technique of montage. Comte de Lautréamont's poetic line "as beautiful as a chance encounter of a sewing machine and an umbrella on an operating table" found form with Surrealism, which borrowed heavily from the ideas of Freudian psychoanalysis to unleash the powers of the unconscious through art by means of strange juxtapositions to create startling effects.

The integrative strategies and techniques of the avant-garde remain to be considered at length within the literature on interdisciplinarity. The avant-garde emphasized radical juxtaposition, particularly collage in all its manifestations, to create a sense of "shock of the new" and "startling effects" that enabled new perspectives and insights. Avant-garde composers, artists, and filmmakers provoked viewers to find common ground between two different entities with the confidence that such common ground was always possible. Many avant-garde innovations would advance further during the rise of intermedia and multimedia as art disciplines in their own right beginning in the late 1940s.

10.4 Intermedia and Multimedia Experimentations after World War II

The period after World War II witnessed an unprecedented mixing of arts to create new art media that had their roots in the avant-garde. Already in 1916, Italian Futurists "declared film to be the supreme art because it embraced all other art forms through the use of (then) new media technology" (Packer & Jordan 2001, p. xx). They saw film as the means toward what they called *polyexpressiveness*, "towards which all the most modern artistic researches are moving" (Marinetti et al. 2001, p. 12). Among the qualities they sought for Futurist cinema was simultaneity, a quality composer John Cage explored with other artists at Black Mountain College in 1948, when he orchestrated an untitled event at Black Mountain College. Cage collaborated with the painter Robert Rauschenberg, choreographer Merce Cunningham, and poets Charles Olson and Mary Richards, among others to create a multidisciplinary work that was based on the concepts of simultaneity and action. The performance scholars Rosemary Klich and Edward Scheer have described the event as follows:

> Numerous artistic forms were employed within the event: as Cage spoke about the "relation of music to Zen Buddhism," Rauschenberg played records on a gramophone and projected slides and film on the ceiling. Merce Cunningham danced through the audience while Olson and Richards read their poetry and Jay Watt sat in the corner and played different instruments. It was significant that these events/processes/performances occurred simultaneously, and could be considered equally important, without any mode being relegated to a supportive role. . . . Performers were given a score which indicated time brackets only—the rest was up to them. The performances were simultaneous events unified by the theatrical frame, and by the audiences' experience. (Klich & Scheer 2012, p. 28)

Cage's experiments were considered to break down the boundaries between the arts, as well as require more active participation of audiences to make meaning of what they were experiencing as art. The painter Allen Kaprow would subsequently explore these ideas though the avant-garde technique of assemblage—the mixing of three-dimensional objects. Kaprow's first Happenings in 1959 expanded assemblages to room environments and involved what the critic and scholar Richard Konstelanetz would later term a "theater of mixed means" (Konstelanetz 1968). Participants (rather than audience members) would take part in a Happening event by moving around three room environments and interacting with the players (rather than actors or performers) according to Kaprow's written instructions disseminated beforehand. In his essay "Untitled Guidelines for Happenings" Kaprow asserted "that audiences should be eliminated entirely. All the elements—people, space, the particular materials, and character of the environment, time can in this way be integrated" (Kaprow 2001, p. 313).

Kaprow's Happenings brought together elements from multiple established art forms—theater and painting—as well as emergent media of installation and assemblage to create works that at the time seemed "in between" art disciplines. In 1965 the Fluxxus artist Dick Higgins published an influential essay in which he coined the term *intermedia*, although he claimed to have borrowed the term from Samuel Taylor Coleridge. Writing a postscript to the text in 1981, Higgins noted that Coleridge used the word in 1812 "in exactly its contemporary sense—to define works which fall conceptually between media that are already known" (Higgins 1984, p. 23). Scholars have since largely dismissed his claims as exaggerated, since Coleridge only used the term *intermedium* as an adjective once in 1812, whereas Higgins succeeded in popularizing the term as an important concept for thinking about new developments in art, even as he eventually lost some of his initial enthusiasm for the term, warning that "it is more useful at the onset of a critical process than at the later stages of it" (Higgins 1984, p. 28). Nonetheless, Higgins's concept of intermedia has been used to describe both the blurring of disciplinary boundaries and artworks regarded as "in-between" established art mediums. The concept of intermedia thus introduced multidimensionality to interdisciplinarity with a sense of place (in-betweenness) and time (simultaneity).

"Intermedia" became a popular term during in the 1960s to describe the experimentations by painters, sculptors, dancers, musicians, and filmmakers associated with the Judson Church and the Fluxxus art movement who freely combined visual arts, sculpture, film, slide photography, and dance in their work. A year after Higgins published his essay in 1965, the term "multimedia" also started to be used, especially for art that involved video, film, and electronic music. The advent of video and personal computing as well as advances in communication technologies during the 1960s eventually shifted the meaning of multimedia: By the early 1980s it focused more on electronic and computer-based art. In contrast to intermedia, multimedia has emphasized the simultaneous multiplicity of art forms while also aligning itself with the technology and art movement, which has prompted Packer and Jordan (2001) to proclaim, "multimedia is emerging as the defining medium of the twenty-first century" (p. xv). While they view integration as "the foundation of multimedia," (p. xxxvi), they also list interactivity, hypermedia, immersion, and narrativity as characteristics, concluding that "the medium's only defining element is its mutability" (p. xxxviii). In a very real sense the multimedia experiments during the 1960s paved the way for the acceleration of the technology and art movement. As Packer and Jordan point out, "it was not until Bell Labs scientist Billy Klüver placed the potential of advanced engineering into the hands of artists in New York that integrated works of art and technology began to flourish" (p. xxi).

10.5 Science, Technology and Art: Hybridity, Research, and Opposing Worldviews

Artists have always been interested in incorporating science and technology in art. As Klüver observed, "technology has always been closely tied in to the development of art. For Aristotle, *Technê* means both art and technology. As they became different subjects they still fed on each other" (Klüver 2001, p. 35). Leonardo da Vinci drew on his skills as an artist to further his studies in science and engineering. Nineteenth-century painters drew on scientific research on light and motion. Beginning with the Italian Futurists, avant-garde artists began to view technology as an art medium in its own right. Lásló Moholy-Nagy experimented with light and making art with telephones while at the Bauhaus, the German modernist precursor for contemporary interdisciplinary arts education. Marcel Duchamp called Alexander Calder's hanging moving objects mobiles in 1932. By the late 1950s, kinetic art was firmly established as a strand of modern art. For the most part, kinetic art explored the aesthetics of motion. In 1960 Jean Tinguely created *Homage to New York*, a machine performance in the sculpture garden of the Museum of Modern art during which a machine that he created with other artists and engineers destroyed itself. Tinguely's machine performance set the stage for postmodernist and poststructualist technological art that coincidentally critiqued the very technologies in which it participated.

One of Tinguely's collaborators, the aforementioned engineer Billy Klüver, cofounded Experiments in Art and Technology, also known as E.A.T, in 1961 to bring artists and engineers together to create new artworks (Packer & Jordan 2001, pp. xxi–xxii). By 1965 the Fluxxus composer Nam June Paik pioneered electronic and new media art by combining television, music, and live performance with the new medium of video. The 1970s saw the rise of new media art using video, television, film, and satellite technologies. With the advent of personal computing, computer-mediated communication technologies, the Internet, and the World Wide Web, the term *multimedia* became increasingly associated with electronic forms of imaging and what Jay Bolter and Richard Grusin call "remediation," the representation of an artwork in another medium (Bolter & Grusin 1999).

The developments in art, science, and technology are too vast and large in scope to be summarized here. Numerous encyclopedic compendiums have attempted to document comprehensively the developments in technology, science, and art even as their authors acknowledge the impossibility of completing the task. Margo Lovejoy's *Digital Currents: Art in the Electric Age* remains an influential pioneering survey after several editions (Lovejoy 2004; first published 1989). Among the most authoritative studies have been those published as part of the *Leonardo* journal series published by MIT Press, such as Steve Wilson's (2002) *Information Arts: Intersections of Art, Science, and Technology* and Steve Dixon's *Digital Performance* (Dixon 2007).

Despite the considerable growth in art and technology scholarship, little emphasis has been placed on interdisciplinarity. Lovejoy (2004), Wilson (2002), and Frank Popper (2007) each note that artists working with science and technology must reconcile with opposing worldviews—that of science and what Wilson (2002) calls "critical theory," that is, the cultural critique of science and technology. Wilson asserts that artists have responded to that opposition three ways: "(1) continue a modernist practice of art linked with adjustments for the contemporary era; (2) develop a unique postmodernist art built around deconstruction at its core; (3) develop a practice focused on elaborating the possibilities of new technology." Wilson adds, "In reality, the work of artists interweaves these approaches" (p. 26).

Two of the three responses Wilson (2002) identifies can be regarded as integrative. The second response, creating art that contains either a reflection on or critique of technology, maintains two opposing views simultaneously without necessarily offering any common ground. Wilson asserts that for artists who pursue deconstruction as art practice, "theory, writing, and art production become intertwined in intimate ways" (p. 27). The third response requires that artists "participate in research activity rather than remain distant commentators, even while maintaining reservations about the meaning and future of the scientific explosion" (p. 28). Wilson furthermore suggests that the third response offers artists the following opportunities:

> Free from the demands of the market and the socialization of particular disciplines, artists can explore and extend principles and technologies in unanticipated ways. They can pursue "unprofitable" lines of inquiry or research outside of disciplinary priorities. They can integrate disciplines and create events that expose the cultural implications, costs, and possibilities of the new knowledge and technologies. (Wilson 2002, p. 28)

Additional integrative techniques can be noted. First and foremost is that of hybridization, a methodological concept borrowed from biology and agriculture. It implies seamless, if not organic, integration of two or more different form or materials. In 1972 James W. Davis identified seven different types of hybrid elements in art (Davis 1972). The result of hybridization, *hybridity*, as a concept has been increasingly used since the 1990s extensively to describe not only technological art but also contemporary art in general (Drucker 2005). Simon Shaw-Miller goes so far as to assert "that hybridity . . . is perhaps the general condition of the arts" (Shaw-Miller 2002, p. 32), a sentiment shared by James W. Davis in his book *Hybrid Culture: Mix-Art* (2007).

Within the constellation of possible intersections between technology and art, the technology itself can be considered as integrative. Immersive art is often used to describe the use of technology and art to create immersive environments such as those produced by virtual reality. Such artworks mix "real-world realities" with those that are mediated (Benford & Giannachi 2011). Network or communications arts are based on the use of communication technologies or computer-mediated communication such as the Internet. Transgenic arts describe the artist creation of new life forms by new combinations of DNA, such as Eduardo Kac's transgenic bunny, Alba, that glowed green under florescent light. The more technological or scientific the art, the greater the possibility of collaborations between artists, scientists, and engineers that can be best categorized as research. Paradoxically, while the interrelations between science, technology, and art are increasingly research based, the theorization of interdisciplinary arts continues to be more associated with arts and humanities scholarship.

10.6 Recent Interdisciplinary Arts Research

By now it should be evident that current notions of the interdisciplinary arts have been to no small extent cobbled together from the past, particularly from overlapping accounts of the *Gesamtkunstwerk*, the historical avant-garde, intermedia, multimedia, and technological arts. New ideas about the interdisciplinary arts are drawing heavily from metaphor. As Klein (1990) points out, metaphors are indispensible tools for both thinking about and doing interdisciplinarity. For example, hybridity remains a central yet still undertheorized integrative metaphorical concept in more recent interdisciplinary arts. First used to describe integrations between art, science, and technology, it has emerged as a fundamental term for understanding contemporary art in general. Its discursive journey from the sciences to the arts as a concept also illustrates Mieke Bal's theory of traveling concepts, which Bal has espoused as fundamental for interdisciplinarity within the humanities (Bal 2002).

10.6.1 Collision as an Emergent Interdisciplinary Arts Metaphor

Collision has emerged as another significant metaphorical interdisciplinary arts concept. In 2005 a group of graduate students organized an inaugural conference investigating the interdisciplinary arts titled *Collision* at the University of Victoria, which was followed by another symposium on the topic the following year. In 2008 a volume of essays from the two meetings was published, and in its introduction the editors explain their choice of metaphor. Noting that the most common image of collision comes not from physics but from popular media—the image of cars colliding—the editors describe the interdisciplinary arts in terms resonant of Wagner: "In this book the productive struggle between two or more art forms or disciplines is described as a radical exteriority, suggesting continual movement while resisting any final unity or acceptance of one form's dominance over another" (Cecchetto et al. 2008, pp. xi–xii).

Distancing the interdisciplinary arts from the interarts model, "where one art form borrows or adopts characteristics from another," the editors embrace instead "Roland Barthes' [*sic*] disruptive notion of interdisciplinarity as an act that results in mutation when 'the solidarity of the old disciplines breaks down-perhaps even violently' (Barthes 1984, p. 56)" (Cecchetto et al. 2008, p. xiii). For these scholars, "this rupturing of boundaries points to the sense in which the term 'collision,' while maintaining its suggestion of forceful impact between two or more distinct masses moving in different directions, also conveys a potentially productive learning from differences" (p. xiii). Elsewhere in the volume, the contributor Tanya Augsburg (2008) cites another passage about interdisciplinarity from Barthes that emphasizes creative innovation: "In order to do interdisciplinary work, it is not enough to take a 'subject' (a theme) and to arrange two or three sciences around it. Interdisciplinary study consists in creating a new object, which belongs to no one" (Barthes 1981, p. 72).

10.6.2 An Interdisciplinary Arts Typology

The *Collision* editors cite Shaw-Miller (2002), who has made an attempt at developing a typology for the interdisciplinary arts based on the philosopher Jerrold Levinson's prior distinctions. Levinson (1984) borrows the concept of hybrid to distinguish three types of "hybrid art forms": (1) juxtaposition, (2) synthesis, and (3) transformation. Shaw-Miller superimposes interdisciplinary typology on Levinson's categories: juxtaposition as multidisciplinary, synthesis as interdisciplinary, and transformation as cross-disciplinary. Examples of multidisciplinary juxtaposition would include Cages's untitled 1952 event at Black Mountain College as well as Philip Glass and Robert Wilson's collaborative opera *Einstein on the Beach* (1976). Synthetic interdisciplinary work would be more evident with Wagner's *Gesamtkunstwerk* as well as collage. Cross-disciplinary transformation is "characterized by an instable relationship between its constituent elements," where "one art form crosses over into the territory of the other(s) as in kinetic sculpture," which Levinson defines as "ordinary sculpture modified in the direction of dance" (Levinson 1984, p. 33). For Shaw-Miller, whether the art is juxtapositional, synthetic, or transformational, "the combining of music and the visual arts draws attention to points of similarity, difference, and contrast" (Shaw-Miller 2002, p. 27). Arguably his attempt at typology does not go far enough, given the recent interest in conceptualizing the transdisciplinary arts.

10.7 Toward Transdisciplinary Arts

The existing scholarship on transdisciplinary arts has yet to catch up to its burgeoning practice. Recently established transdisciplinary arts programs such as the transdisciplinary media arts and technology graduate program at University of California, Santa Barbara, and the MA/MFA trandisciplinary new media program at the Paris College of Art emphasize the intersections between science, art, technology, and new media. The Paris College of Art appears to draw from definitions of transdisciplinarity as a collaborative practice in its program description:

> Designed for those who are interested in exploring the wide-ranging creative field of New Media that goes beyond traditionally defined art and design disciplines, this program employs methods of transdisciplinary practice through collaborative teamwork. Through a shared creative process, students will re-frame their current understanding of different tools, technologies, theories and methods, developing hybrid systems and solutions that go beyond any one discipline. (https://www.paris.edu/departments/in_program/19/66)

The above description points to the transdisciplinary arts as art that is collaborative while transcending disciplinary boundaries altogether. In 2005 Ami Davis described transdisciplinary arts by distinguishing them from the interdisciplinary arts:

> In interdisciplinary pursuits, disciplines collaborate. Scientists and artists, commonly regarded as ideologically opposed practitioners, can intersect and contemplate their common relationships. However, these interacting disciplines ultimately retain their identities as isolated from each other. Transdisciplinary projects have also an agenda to explore common practices among disciplines, but with a more holistic approach. By transcending conventional notions of what appropriate activities within a discipline are, participants attempt to bridge disciplines in innovative ways. . . . In transdisciplinary projects, the traditionally assumed binary nature of art and science is exposed, and not taken for granted. (A. Davis, 2005)

For Ami Davis (2005), the overriding metaphor for transdisciplinary arts is transvergence. In 2012 for the Second Annual Conference on Transdisciplinary Imaging the metaphorical theme was interference as a strategy for art. The proceedings from this conference were published in 2014 as a volume of *Leonardo Electronic Almanac* titled *Interference Strategies*, coedited by Lanfranco Aceti and Paul Thomas. According to Aceti, interference "is a word that assembles a multitude of meanings interpreted according to one's perspective and ideological constructs as a meddling, disturbance, and an alteration of modalities of interaction between two parties. . . . Interfering artworks . . . by their own nature challenge a system" (Aceti 2014, p. 10). For Thomas (2014), "the theme of `interference strategies for art' reflects a literal merging of sources, an interplay between factors, and acts as a metaphor for the interaction of art and science, the essence of transdisciplinary study" (p. 13). Interference is explored as "a key tactic for the contemporary image in disrupting and critiquing the continual flood of constructed imagery," and as "an active process of negotiating between different forces" (p.14). The contributor Anna Munster points out that as a concept, interference has been conceived within physics "as a phenomenon and then technique for generating a diverse range of scientific imaging from the mid-twentieth century onward" (Munster 2014, p. 155). It is an ethical tactic for interfering with static and authoritative contemporary scientific imaging.

10.8 Conclusion

Interdisciplinary arts are thriving, although the scholarship on the interdisciplinary arts has yet to catch up with practice. Views of the interdisciplinary arts have shifted from Wagnerian ideals of a unified total artwork to theoretical considerations of certain current artistic practices. Presently the literature reflects a fascination with latest technological developments, as it borrows heavily from the scholarship on science, technology, and art. As it currently exists, the literature is not only incomplete but also mostly devoid of considerations of interdisciplinary art that foregrounds social, global, and environmental awareness and activism. Consequently, it is out of sync with much of the thriving interdisciplinary developments evident in theater, film, music, performance art, dance, feminist art, disability arts, contemporary art, social practice art, and more. Nonetheless, it is an important discourse to review and consider, as advances in understanding what are the interdisciplinary arts propel the understanding of all the arts forward. It also serves to advance the understanding of interdisciplinarity in general, and possibilities for integrative techniques in particular.

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CHAPTER 11

INTERDISCIPLINING HUMANITIES

A Historical Overview

JULIE THOMPSON KLEIN AND ROBERT FRODEMAN

Any chapter on interdisciplinary humanities begs the question of what constitutes the humanities. The US-based National Endowment for Humanities (NEH) definition is widely cited: "The term 'humanities' includes, but is not limited to, the study and interpretation of the following: language, both modern and classical; linguistics; literature; history; jurisprudence; philosophy; archaeology; comparative religion; ethics; the history, criticism and theory of the arts; those aspects of social sciences which have humanistic content and employ humanistic methods." The NEH definition, however, is only a multidisciplinary sketch. Understanding the nature of interdisciplinary humanities requires tracing a complex set of developments. This overview accounts for their predisciplinary past and interdisciplinary developments over the course of the twentieth century. After presenting a snapshot of two disciplines—art history and music studies—it compares trajectories in two traditionally text-based disciplines—philosophy and literary studies. (Sections 1, 2, and 4 draw on Klein 2005; Section 11.3 draw on Frodeman and Briggle 2016.)

11.1 Early Warrants

The English word "humanities" derives from a cultural movement in ancient Rome under the heading *humanitas*. The term defined both the goal of Roman culture and the arts or studies most suited to expressing it. In his later writings, Cicero designated poetry, geometry, music, and dialectic as the arts pupils should study to ensure full humanity. Romans also shared the Greek notion that certain texts provided insight into the *res magnae*—the great issues of truth, goodness, beauty, and justice. They conceived of the liberal arts as preprofessional education and compendia of information, not methods for systematizing philosophy or organizing erudition. However, the foundation of Roman *artes liberales* was grammar, understood as study of literature and language. Careful study of texts was thought to convey a kind of normative and well-rounded general education. Following suit, the role model of

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the humanist was the orator skilled at influencing public opinion and policy through the rhetorical art of persuasion. Not everyone agreed, though. Aulus Gellius argued those who used Latin correctly, especially Cicero and Marcus Varro, did not give *humanitas* the meaning it was commonly thought to have—the Greek notion of *philanthropa* connoting a friendly spirit and good feeling rather than practical purpose (McKeon; and Crane, in Klein 2005).

Italian humanists were the first to actually be called "humanists." *Umanista* was Latin slang for scholars and teachers of *studia humanitatis* in Italian universities during the late fifteenth century. In shifting the focus of liberal arts education toward rational analysis of texts, Italian humanists turned away from the scholasticism of dialecticians in newly emerging universities of the twelfth and thirteenth centuries. They also shifted the lens back to classical antiquity, although teachers of grammar and rhetoric emphasized classroom aids over ideal products. The role model of humanists changed in kind, refigured as an *uomo universale*, polymath, *cortegiano, bonnete homme*, and scholar-gentleman conversant with a wide range of subjects.

Over ensuing centuries the unity found in classical and humanistic traditions eroded as new subjects emerged. Attempts at unification did not end, however. From the sixteenth century forward efforts appeared in the work of Comenius, Leibnitz, d'Alembert, Kant, Hegel, and von Humboldt. In the seventeenth century, the concept of ages of learning also promoted cultural history as a general framework. Common motifs, themes, and genres fostered synoptic theorizing, the integrative concept of periodization, and practice of interart comparison later dubbed "interdisciplinary arts." The most direct expression was the early Romantic notion of *Symphilosophie*, which attempted to produce unity in *mythos*. Hegel also emphasized "the truth was the whole" in a philosophic system aimed at integrating all areas of human knowledge (Kockelmans, "Science and Discipline"; Graff; and Vosskamp in Klein 2005).

The origin of interdisciplinarity is dated to several historical points. Michael McKeon (1994) tracks its rudiments to the eighteenth century. During the Enlightenment, subjects were assuming increasingly distinct identities as the material and institutional conditions that gave modern divisions of knowledge a sociopolitical foundation were being put into place. Yet a synthesizing counter-movement was also apparent: The encyclopedists based their thinking on analogy, continuity, causal interconnections, and contextual relations that recognized artistic expression and economic behavior are embedded in a network of social, political, and ethical concerns. Others, including Frodeman (2013), date interdisciplinarity's origin to the rise of disciplinarity between 1870 and 1910. During that period higher education was reorganized around 20 to 25 disciplines, each with its own department, major, and curriculum.

Ironically, since they include the oldest subjects, the humanities were last to assume modern disciplinary form. Between the mid-seventeenth and late eighteenth centuries, physics, biology, and chemistry began assuming separate identities, even while still subsumed under the broad category of natural philosophy. Modern use of the term "humanities" is built on distinctions between sciences and humanities and between fact and value foreign to ancient thinking. In fact, the first use of the term "natural science" did not occur until 1834. In the late nineteenth century, the humanities constituted a disparate group of fields, the "least worldly leavings" in the university with the exception of the portion in divinity schools. Interests in "personality" and "society" once explained by myth, theology, and philosophy were relocated to the social sciences and, as they branched off from the broad field of moral philosophy, the remaining and most abstract part—"intellectual philosophy"—was composed of logic, epistemology, and metaphysics. By 1900 "humanities" designated a range of culture-based studies, including literature, philosophy, art history, and often general history. The discipline of history grew rapidly as an independent domain absorbing aspects of politics and economics with a past dimension. Its ambiguous identity as a member of the social sciences or humanities stems from association with moral philosophy and literary inquiry. Art and music lagged behind in departmental formations, but by 1920 were well established at most universities and colleges (Garber; and Kuklick, "Professionalization," in Klein 2005).

Philology was the first major scholarly paradigm in the modern family of humanities disciplines. As was the case with classical study, it implied a larger cultural vision, an *Altertumswissenschaft* aspiring to a total view of civilization with command of its languages and a method capable of integrating disciplines. However, philological science was privileged over a comprehensive and speculative view of culture. Academic theologians also adopted philology as a professionalized method for understanding the Bible, with mastery of Greek, Latin, and Hebrew considered key to comprehending sacred texts. At the same time, Matthew Arnold's model of the social function of literary studies asserted a counter-vision of the organic wholeness of human nature, anchored in a canon of great works that was neither systematic philosophy nor narrow grammatical or literary study. It was a general education encompassing polite literature, Greek science, mathematics, and poetry, and writings of Copernicus, Galileo, Newton, Darwin, Shakespeare, and Goethe. Arnold located human powers of intellect and knowledge, beauty, social life, conduct, and manners in the generality of the species and the interrelations of those powers (Crane; and Graff in Klein 2005).

In the early twentieth century a group Laurence Veysey called the "culture camp" of humanities also asserted a competing vision. They extolled the Renaissance ideal of *litterae humaniores*, the social and moral purpose of education, spiritual idealism, and a conception of culture as process rather than a set of research products (1979, pp. 53–54). Nonetheless, as James Stone (1969) explained, even with counter-visions of the humanities, the disciplining of humanities continued to reinforce segmentation of research and education. As experts developed esoteric investigations in specialized domains, the notion of a shared culture diminished. Decentralization and fragmentation of education hastened. Older unified fields of inquiry began decomposing under centrifugal forces of differentiation. Older unitary principles of the university eroded, and new unifying hypotheses were foreshortened. The general education movement that arose in the opening decades of the century reinscribed a holistic vision of culture, but competing historical- and problem-focused models emerged as well. Over the course of the century a plurality of other developments became aligned with the concept of interdisciplinarity. Although the dominant trend in higher education and research over the twentieth century was the growth of specialization, over the latter half of the century these developments challenged its primacy.

11.2 Twentieth-Century Developments

Early interdisciplinary developments associated with the humanities date to the 1930s and 1940s, in the philosophy of science (the Vienna Circle), comparative literature, and American studies. In the late 1960s and early 1970s new fields emerged, including black studies, women's studies, ethnic studies, environmental studies, and urban studies. The importation of European philosophy and literary theories into scholarship in North America also moved beyond older positivist paradigms in multiple disciplines, along with social and political turns in scholarship, structuralism and language-based psychoanalysis, neo-Marxist criticism, and widening interest in feminist theory and semiotics. Further into the 1980s, an array of practices lumped under the umbrella term "poststructuralism" gained influence, including new historicism, and cultural and postcolonial critique. By the 1990s, multiculturalism was a major theme, and many believed the humanities were evolving into cultural studies. Increasing attention was also paid to the contexts of aesthetic works and responses of readers, viewers, and listeners. The concept of culture expanded from a narrow focus on elite forms to a broader anthropological notion of culture. Calls for a reinvigorated "public humanities" aimed to restore the close link between the humanities and public life in the Roman era, albeit on contemporary ground.

Interdisciplinarity was implicated at every turn. Each movement differed in some way, but together they fostered a new generalism that countered both the modern system of disciplinarity and the culture camp's vision of humanities. The new generalism was not a unified paradigm. It was a cross-fertilizing synergism in the form of loosely shared methods, concepts, and theories about language, culture, and history. A new rhetoric of interdisciplinarity developed in kind. "Plurality" and "heterogeneity" replaced "unity" and "universality," "interrogation" supplanted "synthesis" and "holism," and new "anti-," "post-," and "de-disciplinary" formulations emerged. In the late 1990s the term "transdisciplinarity" also began appearing in association with new theoretical paradigms in cultural studies and critique. In Canadian studies, for instance, Jill Vickers associated the label with movements that reject disciplinarity and its epistemologies in whole or in part, and in some cases generate self-knowledge, including women's studies, Native/Aboriginal studies and cultural studies, communications studies, regional studies, Northern (or Circumpolar) studies, urban studies, and environmental studies (1997, pp. 22, 41).

Two disciplines—art history and music—provide introductory snapshots of discipline-based trajectories of interdisciplinary influence. Tanya Augsburg presents a fuller account of interdisciplinary arts in this volume. In art history, word-and-image studies treating artworks as texts were influential in the 1980s, while critical studies of culture opened larger questions of representation and interpretation. The "new art history" that emerged over the latter half of the twentieth century enlarged the canon to include new stylistic movements and neglected groups. The boundary between high and low or popular art also eroded and new hybrid genres emerged. Scholarship changed in kind. Selma Kraft (1989) identified two drivers of change. One—from the social sciences—accentuated production and use, focusing on political, cultural, social, and economic conditions of artistic production and its reception. The other—closer to the humanities—drew on critical, semiotic, and deconstructionist approaches, especially from literary theory and philosophy. Scholars also incorporated insights from Marxism, political theory, sociology, anthropology, and psychoanalysis (pp. 65–66). Other disciplines and fields increasingly claimed stakes in analyzing and interpreting visual materials as well, fostering a widening field of "visual culture" studies across disciplines and interdisciplinary fields.

The discipline of music provides a fuller illustration. Like art history, it was a borrower from the start, depending on art history for the paradigm of style history and on literary studies for paleographic and philological principles. Synoptic theorizing and the generalist tradition furnished a holistic model of moral, social, and religious development. Musicology was the first major basis for a formal intellectual discipline and, along with ethnomusicology, was regarded as a "humanistic" discipline rather than an "art" of composition or performance. The German *Musikwissenschaft*, which developed in the late nineteenth century, emphasized positivist historiography and stylistic evolution. The object of study was an autonomous work, and the concept of tonality central. In the positivistic paradigm of the late 1950s and early 1960s, empirically grounded facts and historicism were prioritized. Both musicology and music theory also claimed explication of musical works as their disciplinary turf (Trietler; McCreless; Kerman; and Kassabian in Klein 2005).

Positivistic musicology came under scrutiny in the mid-1960s and music theory in the late 1980s. Scholarship expanded as scholars developed greater historical and cultural awareness. Borrowing from other cultures and genres became a major compositional practice, and new hybrid genres such as performance art and multimedia forms challenged traditional boundaries. Marxists critiqued essentialist binaries, including separations of serious and popular music. Poststructuralist critics linked notions of truth with systems of power, calling into question the master narrative of tonality. Postmodernist questions about the validity of universalizing stimulated interest in local, everyday, variable, and contingent aspects of music making. Deconstructive analysis unveiled operations of power related to gender, race, and class and the ways music constructs social identities and spaces. And, with advances in technology, scientific subdisciplines such as acoustics, physiology, psychology, and computing expanded (Shepherd; Kassabian; and McCreless in Klein 2005). Fear of distorting the discipline continues, and historical musicology remains a dominant approach. Yet it is harder to speak in the singular anymore. "Musics," Philip Bohlman concluded, are proliferating and multiplying, along with their meanings (1992a, 1992b).

Two additional examples flesh out a fuller picture of interdisciplinary trajectories, focusing on the oldest of humanities disciplines—philosophy and literary studies.

11.3 Philosophy

Viewing Western philosophy from the perspective of (inter, trans) disciplinarity unsettles the standard categories of philosophic thought.[1] Histories of philosophy frame their accounts in different ways. They tell the story in terms of periods, ancient, medieval, modern, and contemporary, or as a quarrel between ancients and moderns, with "postmodernity" somewhat awkwardly tacked on at the end. Or they tell it in terms of great thinkers: Descartes (or Machiavelli) as the pivot between ancient and modern thought; Frege (or Husserl) as having inaugurated twentieth-century thinking; Wittgenstein (or Heidegger) as the greatest thinker of the twentieth century. Philosophy is divided conventionally into core areas: in the analytic tradition, in terms of metaphysics and epistemology and the philosophy of language; in the continental tradition, in terms of phenomenology, existentialism, and poststructuralism. In recent decades the canon has also been reread in terms of gender and racial categories as a

[1] Parts of this account appear in Frodeman and Briggle (2016), *Socrates Tenured: The Institutions of 21st Century Philosophy*.

history of exclusion. Yet despite the variety and richness of these accounts, all of them pass over a crucial juncture: the disciplining of philosophy within the modern research university in the late nineteenth century. Philosophy was defined as a discipline, which is to say as a regional ontology, whose focus was on philosophizing with other properly trained and certified professionals.

Interdisciplinarity does not form part of the philosophical lexicon—even as the issues it raises move just beneath the surface. This incongruity is most glaring in the figure of Socrates. The patron saint of philosophy was an *avant la lettre* transdisciplinarian: He rejected expertise and did his philosophizing via conversations in the agora, with people from all walks of life. But this fact, so central to Socrates's practice, receives no attention by twentieth- and now twenty-first-century philosophers. Philosophers pride themselves on leaving no assumption unchallenged, but since the rise of the modern research university, thinkers have scarcely raised the question of whether there is something improper in restricting their work to the disciplinary tasks of training students and writing for other professional philosophers. They have ignored the question of whether philosophy is, or should be, a discipline like other disciplines across the university.

Prior to what Steve Fuller (2016) has called the neo-Kantian settlement, philosophers had had no central home. They could be found anywhere—serving as diplomats, living off sinecures, functioning as clergy, grinding lenses, even housed within a college or university. That is, philosophers were as much transdisciplinary as disciplinary thinkers. This constituted more than merely a fact of location: While some philosophers wrote for other experts, a sizable portion of philosophic energies were devoted to live and pressing societal issues, not abstractly within the pages of professional journals (which in any case did not exist), but out and about in the world. Today we would call this a co-productionary model of knowledge.

These earlier, predisciplinary philosophers were also interdisciplinary thinkers. Figures like Descartes and Hume interacted with scholars of all types. But here the term "interdisciplinary" must be used advisedly. Before Kant and the development of modern disciplinary culture, the scientist and the philosopher were often one and the same person. The intellectual and social roles had not yet diverged. Moreover, not only did their work cross disciplinary boundaries, which were in any case much more fluid than they are today, but also, and more fundamentally, it was the distinctive task of the philosopher to create, go beyond, erase, and redraw the boundaries and categories of thought.

Philosophers once thought that there is something problematic about treating philosophy as simply one discipline alongside the others. It was once understood that, in addition to fine-grained analyses, philosophy offered perspectives that undergirded, capped off, or synthesized the work of other disciplines such as physics or biology, and then connected those insights to our larger concerns. Such work lost favor in the twentieth century—dismissed as *Weltanschauung* philosophy by analytic philosophers, and as foundationalism by continental philosophers. Serious philosophers became inhabitants of the research university. Against the inclinations of Socrates, philosophers became experts like other disciplinary specialists. They debate issues as they were defined in professional journals rather than by the life-world; their students were expected to master a discourse directed toward other professional philosophers rather than to the world at large.

In twentieth-century philosophy, acceptance of the disciplinary culture of the modern university was not viewed as a problem. No longer framing discussions in terms of everyday questions concerning truth, goodness, and beauty, epistemology turned into abstract considerations on the nature of truth, ethics into meta-ethics, and social and political philosophy into general reflections on the nature of freedom and social responsibility. The institutional housing of knowledge—disciplines, departments, professional societies, and peer-reviewed journals—developed as a matter of course. This inattention is reflected in the fact that until quite recently the field of interdisciplinary studies has attracted few philosophers—although this is changing today, with work being done by O'Rourke, Fuller, Schmidt, Hoffman, Holbrook, Frodeman, and others.

Early twentieth-century philosophers were faced with a dilemma: With the natural and social sciences claiming to map the whole of knowledge, what role was there for philosophy and the humanities generally? There were several possibilities: Philosophers could serve as

- synthesizers of academic knowledge;
- formalists providing the logical undergirding for research and education;
- translators integrating the disciplines, and helping to bring the larger insights of the academy to the world at large;
- disciplinary specialists who focused on recondite philosophical problems in ethics, epistemology, aesthetics, and the like;
- practitioners working in the field with people from all walks of life;
- or a combination of some or all of these roles.

But in terms of institutional realities there seems to have been no choice: philosophers had to become scientific, embracing the structure of the modern research university, which consists of a spread of specialties demarcated from one another. Disciplinary culture became the standard for what would count as proper philosophy. It was the only way to secure the field's survival. But it was not as if philosophy found a familiar niche in a new institutional ecosystem, one that allowed it to continue to do what it had long been doing. Rather, philosophy itself changed. It became a creature of disciplinarity. Though few philosophers recognized the shift, preferring to believe that they and Socrates remained members of the same species.

The christening of philosophy as a discipline was an act of purification that gave birth to the now commonsense view of the field. Over the course of the twentieth century philosophers abandoned John Dewey's public philosophy for W. V. O. Quine's way of treating philosophy as a technical exercise. While it is possible to point to philosophers who *work with* (rather than merely talk about) nonacademic problems, for the vast majority of philosophers the lack of societal engagement has become a sign of intellectual seriousness. As Quine himself put it in a 1979 *Newsday* piece (reprinted in Quine 1981), philosophers do not "have any peculiar fitness for helping . . . society."

To reiterate the main point: The well-regarded historian of analytic philosophy Scott Soames (2016) has noted the interdisciplinary aspects of twentieth-century philosophy. While granting that the logical empiricists of the 1930s through the 1950s viewed philosophy as having its own distinctive subject matter, Soames points out that philosophers such as Frege, Russell, Gödel, and Turing made crucial contributions to the creation of set-theory within mathematics and the theory of computation that laid the groundwork for the digital age. Similarly, philosophers such as Carnap and Kripke provided a background for studying meaning in language, just as Jeffrey made fundamental contributions to decision theory, advancing the fields of political science and economics. Philosophers today continue to make important contributions to cognitive psychology and neuroscience.

But Soames ignores the fact that most of these interdisciplinary effects were the result of passive diffusion rather than active engagement. And he is silent on the other roles that philosophers had once played—as synthesizer, translator, field practitioner, or gadfly. In his 2005 *Philosophical Analysis in the 20th Century* , in an epilogue titled "The Era of Specialisation," Soames notes, "philosophy as a whole—has become an aggregate of related but semi-independent investigations, very much like other academic disciplines." He concludes by suggesting, "what seems to be the fragmentation in philosophy found at the end of the 20th century may be due to more than the institutional imperatives of specialisation and professionalisation. It may be inherent in the subject itself" (cited in Rorty 2005). This is certainly the case for the last 125 years of philosophy; but whether this is a reflection of philosophy's essential nature or a matter of its current institutional housing remains open to debate.

11.4 Literary Studies

Prior to the modern discipline's formation, "literature" encompassed a broad range of meanings, from polite letters and poetry to anything written, though especially serious writing. The subject appeared in English academies during the late seventeenth century, though literature as imaginative writing did not become prominent until the late eighteenth century. From roughly 1860 to 1915, philology and literary history were the major scholarly practices in the form of editing and annotating texts; compiling bibliographies, dictionaries, and concordances; conducting source and etymology studies; discovering facts; and writing biographies and literary and intellectual histories. In the 1930s and 1940s, criticism became the dominant practice. One strain, led by a group known as the New Critics, emphasized aesthetic formalism in close readings of poems as organically unified objects. In placing moral and social functions of literature within the internal structure of a text, they affirmed the timeless universality Aristotle attributed to literature, rendering historical and cultural change extrinsic to literary scholarship. The other strain, led by the Chicago Critics, emphasized theory and argued for a pluralist approach and humanist moralism concentrated on qualities literature shares with philosophy, ethics, and general ideas. Both strains, though, held that the integrity of the discipline was threatened by nonliterary interests (Graff; Miller; Leitch; Dionne's "Introduction"; and Weber in Klein 2005).

New Criticism did not establish complete hegemony, however. In the 1930s, teaching English as a second language was professionalized as a branch of applied linguistics and, in the 1940s, creative writing gained a place. Many younger critics with generalist inclinations moved toward literary journalism, and a group known as the New York Intellectuals conceived of literature as a cultural phenomenon open to multiple points of view. Marxist and sociological analysis also fueled cultural criticism. Yet while formalist methodologies continued to hold sway, their dominance loosened as interests expanded. In Europe, interdisciplinary research was promoted as the model for a regenerated study of literature opposed to strict formalism and open to historical awareness. By the mid-1950s similar voices were also being heard in the United States in the name of "multiple interpretation," "multiple parallelism," and "multiple causation" (Greenblatt & Gunn; Russell; Robbbins; Bender; Cohen;

Herman; and Beck in Klein 2005). Tensions between the intrinsic and the extrinsic, however, continued. The rhetoric of interdisciplinarity abounds in Barricelli and Gibaldi's 1982 *Interrelations of Literature*, with talk of "interplay," "inherent" ties, "reciprocal process," "interpenetration," "interaction," "symmetries," and "symbiotic" and "complementary" relations. At the same time, literature was still deemed "the hub of the wheel of knowledge."

The 1992 *Introduction to Scholarship* published by the Modern Language Association differed. The most notable contrast was an entirely new category of representation—cross-disciplinary and cultural studies. It contained chapters on interdisciplinary, feminist and gender, ethnic and minority, border, and cultural studies. Disciplinary relations were also more expansive than a decade earlier. The chapter on language, culture, and society acknowledged the impact of theory, women's and gender studies, the role of the computer, and interdisciplinary interests in writing. And heightened interest in the social contexts of language used stimulated studies ranging from global theories of orality and national language policy to turn-taking in conversations. In a chapter mapping interdisciplinary approaches, Giles Gunn identified an even wider range of practices. The simplest way of mapping them, tracing the relationship of one discipline to another, reveals practices such as psychoanalytic criticism and reader-response criticism in the relationship of literature and psychology. A different picture appears when asking what new subjects and topics have emerged, such as the history of the book and the ideology of gender, race, and class. Each topic, in turn, generated further investigations.

Ultimately, Gunn concluded, the result of interdisciplinary study, if not its purpose, is to dispute and disorder conventional understandings of relations between origin and terminus, center and periphery, focus and margin, inside and outside: "The threading of disciplinary principles and procedures is frequently doubled, tripled, and quadrupled in ways that are not only mixed but, from a conventional disciplinary perspective, somewhat off center." In the 1980s, for instance, new historicism moved beyond New Criticism's emphasis on the verbal icon and literary text as a self-contained, formal, and thematic unity. Scholars shared social historians' challenge to consensus histories and a semiotic view of culture, signaled by keywords of "interplay," "negotiation," and "circulation" in a shifting conceptualization of history from "background" to a "shared code" in a network of practices, beliefs, and institutions. When established categories are defamiliarized, character, language, and theme are not apportioned solely to literary scholars, "primitive" customs to anthropologists, and demographic patterns to social historians. Nonetheless, disciplinary economies still operated. The defining rubrics of the Enlightenment framework in eighteenth century studies were aesthetic autonomy, authorship, disinterestedness, and gendered sexuality. New historicism, cultural materialism, feminist literary history, and deconstruction all transformed thinking about these rubrics while crossing boundaries separating individual arts from each other and from historical, scientific, and social scientific discourses. Yet familiar tensions between the "literary" and the "extraliterary," continued to appear (Greenblatt; Hermand; Beck; and Bender in Klein 2005).

Audience-oriented criticism is another case in point. It emerged from social, intellectual, and literary developments in Germany during the late 1960s. As the subfield evolved, it moved beyond German *Rezeptiongeschichte* into a general view incorporating social and political histories of readership. Yet as audience-oriented criticism and reader-response theory took root in literary studies, art history, and sociology, it was often folded back into the internalist primacy of word, image, and behavior. Others, though, had a more transdisciplinary vision (Suleiman 1980, pp. 6–7). Commenting on changes in eighteenth century studies, John Bender contended, "It is one thing to compare literature with the other arts or with—shall we say—philosophy, conceived as uniquely structured disciplines, and quite another to treat novels, paintings, buildings, logical treatises, legislation, and institutional regulations as texts participating in the complex and contestatory processes through which societies define and maintain the structure not only of their institutions but of human entities" (1992, pp. 87–88). In what became a widely cited warrant for a transformative view, Roland Barthes (1977) had argued earlier that "Interdisciplinarity is not the calm of an easy security." It begins when the solidarity of existing disciplines breaks down, signaled by an "unease" in classification. Change, though, appears more often in the form of an epistemological slide than a sharp break.

Once again, claims of radical change were overstated. In a widely read polemic, Stanley Fish (1985) challenged the underlying logic of new developments. As an agenda, he contended, interdisciplinarity seemed to flow naturally from imperatives of left culturalist theory. Deconstruction, Marxism, feminism, radical neopragmatism, and new historicism were critical of two kinds of boundary making: the social structures by which lines of political authority are maintained, and the institutional structures by which disciplines establish and extend territorial claims. Transgressing boundaries, Fish countered, is a subversive process—a *revolution tout court*. However, any strategy that calls into question the foundations of disciplines theoretically negates itself if it becomes institutionalized. The multitude of studies and projects, he maintained, are not radical. They center on straightforward tasks requiring information and techniques from other disciplines. Or, they expand imperialistically into other territories. Or, they establish a new discipline composed of people who represent themselves as "antidisciplinary" but become a new breed of counterprofessionals. As usual, not everyone agreed. Gunn countered Fish's conservative and pessimistic political stance, claiming it perpetuated the dualism of disciplinarity and interdisciplinarity while reinscribing static structure. The radical claim that interdisciplinarity will open the mind is as misleading as the conservative claim it will leave the mind closed. Others challenged Fish's underlying assumption that disciplines are coherent or homogeneous and that interdisciplinary is synonymous with the quest unity of knowledge.

What implications follow for the field in the twenty-first century? "Literature as it was," John Carlos Rowe answered, "can't be saved." The term now encompasses older texts and "extraliterary" materials such as letters, diaries, films, paintings, manifestos, and philosophical, political, psychological, religious, and medical treatises (1992, p. 204). The structural trend of the discipline, Ann Middleton further reported, is moving toward topical and interest-group fragmentation, while "text," "theory," and "discourse" have become boundary concepts across disciplines (1992, p. 23). Resistance to formalism and extremes of specialism are widespread as well, new forms of text are being studied, and the repertoire of explanatory tools and frameworks has expanded. In the aggregate, practices of cultural, lesbigay, and race studies also signal a new period in the history of the discipline. At the same time, Francis Oakley (1997) found, changes in curriculum have occurred primarily through addition, not substitution. Furthermore, W. B. Carnochan contended the coherence of the discipline never existed. The early split of North American literature and language departments into three areas—philology, literature as moral uplift, and rhetoric and composition—is still present in the guise of theory, literature as political and ethical understanding, and rhetoric and composition. The first and most prestigious variant—literature and theory—now includes cultural, media, gender, and Third World studies. Composition is the second variant, and creative writing the third. Many departments also include film studies, and English as a second language (qtd. in Hutcheon 2000, p. 1722).

11.5 Interdisciplinarity and the Future of the Humanities

A crisis motif has long characterized accounts of the humanities: In 2011 the National Humanities Center president Geoffrey Harpham noted, "Crisis has become a way of life. What would the humanities be without their crisis?" The answer to this crisis, according to Harvard University's 2013 "Mapping the Future" report, is to focus on elements such as the development of a "freshman-year challenge" during orientation, the creation of arts and humanities i-labs, and the funding of new faculty positions. Others see these proposals as merely business as usual: Folks (2013) criticized the Harvard report for ignoring issues such as increasing specialization and the production of recondite research of interest only to other specialists, and for seeing the crisis as merely a matter of misbegotten public perceptions.

Interdisciplinarity has been offered as a remedy to claims of academic irrelevance across the academy. In the case of the humanities, whether for good or ill, the radical vision of a postdisciplinary academy has not materialized. However, inter- and transdisciplinary efforts across the humanities suggest that these fields are responding to the changed landscape of twenty-first-century society, in several ways:

- an expanded set of materials and scholarly approaches that counter the status of disciplines as isolated domains
- the erasing of boundaries between the humanities and social sciences, following Geertz's (1980) notion of "blurred genres" and Bal's (2002) notion of "traveling concepts" that appear across disciplines and academic communities
- a turn from "unity" of knowledge and culture to "unifying" strategies framed by differing contexts
- a shift in the role model of an interdisciplinarian from a polymath to Carp's (1996) notion of the "boundary rider," skilled at walking the borders of disciplinary expertise and interdisciplinarity
- the development of transdisciplinary and entrepreneurial approaches to the humanities (e.g., Briggle 2015) where humanists work in real time with partners outside the academy

None of these trends is well established, and all face the challenges of declining funding within a culture increasingly focused on the bottom line. Nonetheless, these initiatives suggest that the oldest of disciplines and fields of humanities have the potential for new relevance both within and outside the academy.

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PART III

INTERDISCIPLINARY FIELDS

CHAPTER 12

DIGITAL HUMANITIES

The Role of Interdisciplinary Humanities in the Information Age

CATHY N. DAVIDSON AND DANICA SAVONICK

The humanities today are vibrant, interdisciplinary, and diverse in nature. Moreover, the need for a humanistic perspective is urgent. Although the *New York Times* suggests, "In Tough Times, the Humanities Must Justify Their Worth" (Cohen 2009), the humanities are indispensible in all times, and never more so than in an era where interactive digital technologies offer abundant creative and scholarly possibilities. The intersection of the humanities and technology raises a variety of personal, ethical, psychological, social, cultural, spiritual, and political concerns.

12.1 Defining an Interdisciplinary Field

So far as modern technologies are concerned, the interdisciplinary humanities look in two directions. They apply and develop tools to aid the study of the humanities in new and complex ways. At the same time, humanists challenge our era of technology by asking enduring questions with a new purpose: What does it mean to be human? In what Erik Brynjolfsson and Andrew McAfee (2014) call the "second machine age," an era in which "the robots are coming," the question of what it means to be human takes on new urgency.

The disciplines that traditionally constitute the humanities include philosophy, religion, literature, linguistics, history, anthropology, and the history and analysis of the arts. The interdisciplinary humanities field most invested in responding to the demands of the Internet era is known as the "digital humanities." Digital humanists are asking profound questions about life in the information age. These include the cost of our privacy, the importance of free speech, the disappearance of leisure time, the rearrangement of the workforce, the role of human intelligence and human agency in an era of automation, and the full range of questions around equity, access, inclusion, and exclusion that are part of our digital era. To answer these questions, digital humanists draw on the insights of new media studies, critical code studies, software studies, game studies, cultural studies, and digital literacy. Digital

Davidson, C. N. and Savonick, D., *Digital Humanities: The Role of Interdisciplinary Humanities in the Information Age*. In: *The Oxford Handbook of Interdisciplinarity, Second Edition*. Edited by Robert Frodeman, Julie Thompson Klein, and Roberto C. S. Pacheco: Oxford University Press (2017). © Oxford University Press.
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humanities (often known as DH) practitioners apply humanistic and artistic knowledge to the worlds of technology, engineering, computational sciences, industrial design, natural sciences, business, law, and medicine.

Taken together, all of these strains in digital humanities contribute to a complex, changing, and multifaceted interdisciplinary subfield—one that is difficult to succinctly define. In *Debates in the Digital Humanities* (2012), Matthew Gold dedicates an entire section (four chapters) to the task of separating out the strands of the digital humanities. Gold identifies two main trends within digital humanities: those who "use new digital tools to aid relatively traditional scholarly projects and those who believe that DH is most powerful as a disruptive political force that has the potential to reshape fundamental aspects of academic practice" (Gold 2012, p. x). According to Gold, digital humanities practitioners ask questions about new research and pedagogical methods amid a climate of changes in the larger academic ecosystem. In many instances, the affordances of digital technologies, such as open-access online publishing, challenge existing disciplinary protocols for peer review, scholarly publishing, and evaluating scholarly productivity to determine hiring and tenure.

In another effort to define digital humanities, the authors of the "Digital Humanities Manifesto 2.0" describe the digital humanities as "an array of convergent practices that explore a universe in which: a) print is no longer the exclusive or the normative medium in which knowledge is produced and/or disseminated . . . and b) digital tools, techniques, and media have altered the production and dissemination of knowledge in the arts, human and social sciences" (Lunenfield et al. 2009, p. 2). As both of these examples illustrate, digital humanities practitioners aim to teach and produce knowledge for a world in which information is readily (though unevenly, and oftentimes inaccurately) available through the Internet.

Many digital humanities scholars are challenging the established disciplines, hierarchies, and epistemologies that have ruled academia since the twelfth century, when Oxford University was founded. While the humanities have historically "shaped lives, conveyed critical skills, provided a moral compass for human experiences, given pleasure and satisfaction, [and] inspired acts of generosity and heroism," new technologies demand that we ask fundamental questions about value, interpretation, and the ethical implications of our decisions (Lunenfield et al. 2009, p. 11). The authors of the "Digital Humanities Manifesto 2.0" propose saving the humanities' "core methodological strengths: attention to complexity, medium specificity, historical context, analytical depth, critique and interpretation" (Lunenfield et al. 2009, p. 2), while inviting us to interrogate traditional disciplinary ways of knowing. Why, they ask, could we not have departments that are better suited for our contemporary historical moment? The imaginative examples they offer include "vocal studies," "erasure," "comparative literature and media," "cultural mapping," and "cultural analytics." Inspired by the Internet's utopian promise of peer knowledge production, the authors of the manifesto commit to collaboration over individualization, authorizing previously discredited epistemologies, and leveling academic hierarchies.

The theorist of interdisciplinary studies Julie Thompson Klein has recently analyzed several decades of work on interdisciplinarity to formulate the "boundary work" of digital humanities. Throughout *Interdisciplining Digital Humanities*, Klein analyzes what she terms the "boundary work" of the digital humanities: the "claims, activities, and structures by which individuals and groups work directly and through institutions to create, maintain, break down, and reformulate between knowledge units" (Klein 2015, p. 5). Her witty and incisive taxonomy of the kinds of digital humanities currently available illustrates the extensive and complex work of this new field:

> They are as diverse as a scholar in literary studies designing a digital collection centered on a single author, an anthropologist or a historian creating a computer visualization of an ancient site, a music instructor mapping sound patterns in the canon of a composer while creating an electronic music curriculum, an artist mounting a multimodal installation while involving students in its production, a professor of Italian producing a digital archive for an entire historical period while directing a humanities lab, a scholar in women's studies doing research on the relationship of the body and technology and a librarian building an online Digital Humanities research guide for faculty and students. (Klein 2015, p. 5)

These, Klein argues, are but a "few examples" of the many forms of "digital humanities," a field that is "multidisciplinary in scope . . . interdisciplinary in integrative work and collaborative practices . . . [and] transdisciplinary in a broad-based reformulation of the humanities that places technology and media at the heart of research and teaching, and in embedding critique in all practices and engaging the pubic sector" (Klein 2015, p. 32). Perhaps more than any other area of the academy, the digital humanities have succeeded in making linkages across disciplines that are radically disparate in focus and methodology.

Many interdisciplinary digital humanists argue that their job is to bring clarity, critique, and analysis to the murky social crises of our era. In this vein, digital humanists define areas of society that have become problematic because of new technological developments or because of unequal access to new technologies. For example, the media scholar Ethan Zuckerman (2013) pinpoints the problem of a partially and differentially connected world. He terms this "incomplete globalization," and explores how "homophily" (love of the same) persists into the networked era. When people choose to engage with, like, and follow like-minded people and institutions, they cordon themselves off and reinforce their system of beliefs. In contrast to the Internet's promise of cosmopolitanism, Zuckerman argues that we too often engage with online sources that bolster our narrow understandings of the world, or even heighten our prejudices and beliefs.

Scholars including Anne Balsamo (1996), Jessie Daniels (2009), Lisa Nakamura (2008), and Tara McPherson (2012) have also raised critical questions about the Internet and social change. They ask how Internet culture, new media, and digital technologies have both reconfigured and reinscribed traditional understandings of race and gender. Many of these scholars caution against either techno-optimism or technopessimism, instead inviting us to understand new technologies as "affordances" that make certain things quicker, easier, and more efficient—including racism, misogyny, and homophobia. Several of these scholars have created FemTechNet (2015), "an activated network of scholars, artists, and students working on, with, and at the borders of technology, science, and feminism." These scholars identify the problems of sexism, antifeminist harassment, and violence—especially as they intersect with technology—and work to combat these through analysis, tools, and activism.

Another recent example of the digital humanities in their fullest articulation can be seen in a 2014 conference, "Can Analysis of Big (and Sometimes Messy) Data Facilitate Collaboration?" The conference brought together scholars from diverse institutions and fields—from computer science and mathematics to English and history—to consider data analysis and visualization, online publication, peer-to-peer open assessment, online mentoring, scholarly social networks, and alternative metrics for evaluating academic achievement.

The scholars explored what could be achieved by taking control of data mining, diverting the analytical techniques used by the NSA and Google toward more ethical, socially just ends. The conference was organized by the Humanities, Arts, Science, and Technology Advanced Collaboratory (HASTAC; hastac.org), an open online scholarly network founded in 2002 that brings together scholars across disciplinary and institutional divides to analyze such issues. With more than 14,000 network members worldwide, HASTAC exemplifies the centrality of interdisciplinary humanities to the contemporary world.

The range of topics included in the call for papers for the 2015 Digital Humanities conference on "Global Digital Humanities" demonstrates how the interdisciplinary digital humanities are both heterogeneous and capacious. This annual conference is organized by the Alliance of Digital Humanities Organizations (ADHO), one of the leading professional associations for digital humanists. Conference participants are invited to submit abstracts related (but not limited to): "humanities research enabled through digital media, data mining, software studies, or information design and modeling; computer applications in literary, linguistic, cultural, and historical studies; and digital arts, architecture, music, film, theatre, new media, digital games, and related areas." The 2015 HASTAC conference, "Exploring the Art and Science of Digital Humanities," focused more explicitly on the activist side of digital humanities with panels on diverse topics such as "Women of Color Feminisms and Digital Production Pedagogy," "Affordances and Limits of Post/Anti/Decolonial and Indigenous Digital Humanities," and "Feminist and Embodied Perspectives on Social Media and Social Justice."

In addition, the conference challenged the traditional convention of having a well-established scholar give the keynote speech, and instead showcased the voices of early-career scholars, and artist-activist practitioners. As these conference agendas make clear, the digital humanities use new computational tools to help in the analysis and interpretation of what are often considered to be traditional or field-based humanistic objects of study (Schreibman et al, 2008). They also work to model better academic practices that are attuned to the inequities of class, racial, and gender privilege—long-standing social issues that extend into the digital, networked era.

12.2 Historicizing the Interdisciplinary Digital Humanities

Understanding digital humanities requires not only identifying its constituent features and intellectual ambitions but also understanding the time and place in which it was conceived. In the 1990 essay "The Emergence of Cultural Studies and the Crisis of the Humanities," Stuart Hall emphasizes that the establishment of any new field must be situated within the political, theoretical, educational, and economic circumstances from which it arises (Hall 1990). To understand the birth of a new interdisciplinary field, then, is to be cognizant of those historical and institutional exigencies that inspired it, and against which it responds.

The digital humanities have emerged in response to the current epistemic transformations in culture and society. According to Robert Darnton (2008), the world has seen four great Information Ages. He defines the first happening with the beginning of writing systems in the Middle East in around 4000 BCE. The second is the invention of movable type in China in the eleventh century AD and, with Gutenberg, in Europe in the fifteenth century. He sees the democratization of mass printing and mass literacy in the West in the late eighteenth- to mid-nineteenth century as the third great Information Age. The present Information Age, he argues, is by far the most influential, rapid, extensive, and global in impact and nature. The technological changes of the last decade—the proliferation of social media, the increasing accessibility of wireless Internet, the advancement of data storing, mining, and visualization techniques—are so vast that they are rearranging societies, politics, culture, science, and economics worldwide.

Seen within this larger frame, the Information Age is less significant for its technology than for its rearrangement of all of the aspects of human life with which the humanities concern themselves. In literary fields, this might include such crucial issues as narrative, authorship, publication, and the creation of new multimedia, interactive, and imaginative virtual worlds (environments such as Second Life or Minecraft, for example, but also narrative games, fantasy games, and other imaginative virtual spaces). In linguistics, the social codes embedded in computer code are a ripe new area of study. So is careful analysis, from a multicultural perspective, of the cultural and scientific assumptions about mind, nature, logic, cognition, and categorization that form the basis of artificial intelligence as well as hypertext and other markup languages. Indeed, new technologies are raising key issues for philosophy, the arts, and music. History puts all of these vast and various changes into perspective.

We can also trace the emergence of the specific term "digital humanities." The digital humanities have roots in the long history of bibliographic methods going back to the great bibliographers of the nineteenth century, in philological and archival traditions, and in newer fields including library and information science (McCarty 2005). Matthew Kirschenbaum (2012) traces the emergence of the term "digital humanities" to a 2001 conversation among editors, specifically a remark by John Unsworth, which resulted in the 2004 publication of the Blackwell *Companion to Digital Humanities*. Many scholars agree that "digital humanities," evolved from the earlier "humanities computing" and is now the more prevalent usage (and, for most purposes, interchangeable with it). The digital humanities were formalized through the emergence of the ADHO in 2005 and the launch of the National Endowment for the Humanities (NEH) Digital Humanities Initiative in 2006. In 2008, the NEH established an Office of Digital Humanities, offering grant programs to address the cultural changes that have emerged in response to networked digital technologies.

One particularly notable feature of the digital humanities is their overt attempt to cross the divide of the "two cultures" that C. P. Snow (1959) famously mapped long ago. For Snow, there was a virtually unbridgeable gap between the world of the arts, humanities, and interpretive social sciences on the one side and, on the other side of the divide, the world of science and technology. Snow demarcates this shift as beginning in the late nineteenth century. Until then, divisions between the "scientific" and "humanistic" were by no means fixed. Sir Isaac Newton, for example, was an astronomer, a physicist, a mathematician, a theologian, a philosopher, and an alchemist—with no contradiction across those domains. Galileo, too, was a mathematician, astronomer, and a philosopher. In the mid-nineteenth century, Charles Darwin's Cambridge degree was in theology and his motivation to study biological diversity came as much from his abolitionist leanings as his scientific ones. Even in the early twentieth century, Einstein credited the philosopher David Hume, as well as contemporary physics, for his thinking about relativity.

However, since the late nineteenth century on, formal education has strongly reinforced a divide between science and the arts. The research university has contributed by promoting an increasingly fragmented curriculum and methods of training. Along with the schism, there has been a value judgment, with more and more weight being placed on the scientific *versus* the humanistic and artistic side of the disciplinary equation. There is a hierarchy, with science at the top of the intellectual heap. One manifestation of this disparate valuation of the scientific is in the ways more and more areas of the social sciences have sought to define their methods as "scientific." Another is seen in the application of so-called scientific (and often, pseudo- or quasi-scientific) assessment and evaluation measures for education, from K-12 to the university level. Unquestionably, for several decades, institutional power and cultural authority have accrued to the quantitative side of the "two cultures" equation. Even now there is a clear divide in digital humanities between the more technology-oriented scholars and others who are interested in the social and cultural implications of technology, but who have no interest or expertise in developing technological skills of their own. There remain, even within the interdisciplinary field, differing expectations of technical literacy.

The digital humanities are certainly not going to rectify a balance that has tipped too much in one direction for the last hundred years. However, the digital humanities do require interdisciplinary revaluing, relaying, and remixing across, between, and among opposite areas in this cultural divide. In *Facilitating Interdisciplinary Research*, a comprehensive report by the National Academies of Science, four drivers are listed for interdisciplinarity: the inherent complexity of nature and society; the desire to explore problems and questions that are not confined to a single discipline; the need to solve societal problems; and the power of new technologies (Committee on Facilitating Interdisciplinary Research 2005, pp. 2, 40). To this list digital humanities would add a fifth driver: the desire for an interactive, collaborative, participatory method of research and learning that capitalizes on the power of new technologies and the customizing skills youth bring to the college classroom today.

Indeed, one of its pedagogical motivations is a conviction that youth today, especially those born after 1991 (the official "birthdate" of the commercially available Internet), do not, as a matter of everyday and informal learning, intuitively make the distinction between "art" and "science." In contemporary customizing digital media culture, a young person might, for example, be writing code for a multiplayer game or editing a video to upload to YouTube and the next moment might be designing a new, fanciful world for Minecraft. To which side of the "two cultures" divide does that belong? Moreover, how can we maximize the affordances of new technologies to make education more responsive to the digital world?

12.3 The Digital Humanities and Interdisciplinary, Student-Centered Pedagogy

While information technology (IT) is evident in every aspect of the university campus, academe (and formal education in general) has been slower than commercial industries in using new digital forms of learning and the new skills of young learners. Digital humanists are among those addressing the need for structural changes in educational institutions. They emphasize the importance of new curricula, the possibilities of collaborative learning in virtual environments, and the need for radical interdisciplinary restructuring of the academy. Similarly, new forms of teacher training—at all levels, kindergarten to professional school—are crucial if there is going to be a pedagogy appropriate for new global, participatory forms of learning (Brown et al, 2008; Davidson & Goldberg 2009).

The digital humanities are as much about teaching as they are about research. Traditionally, learning has been the province of humanists: from the early twentieth-century pragmatist John Dewey's writings on progressive education to the mid-twentieth-century works of critical pedagogy such as Paulo Freire's *Pedagogy of the Oppressed* (1968/1970) and bell hooks's *Teaching to Transgress* (1994). More recently, digital humanists have been vocal proponents of using digital technologies to facilitate experiential, peer-led, and participatory learning that will help better prepare students for the digital world. While many digital humanists also work in composition and rhetoric, a field known for its commitment to developing student-centered, peer-driven classrooms, recent efforts have sought to bring the insights of peer learning and student-centered pedagogy to classrooms across the disciplines (see, for example, the interdisciplinary, online *Journal of Interactive Technology and Pedagogy* and the work of *Hybrid Pedagogy*).

One way this occurs is through an emphasis on the critical and creative work of "making"—or in the parlance of computer programmers, "hack" as well as "yack." Making invites students to learn digital literacy through hands-on experiences with online software and digital platforms (ideally ones that are free, open-source, and open access). The authors of the "Digital Humanities Manifesto 2.0" understand making as both *poeisis* (Greek for "making"; also the root of "poetry") and "design carried out in action, the modeling and fabrication of intelligent things, the generative and re-generative aspects of creation and co-creating" (Lunenfield et al. 2009, p. 8). Making, in this sense, is a version of praxis: It values hands-on-learning as an activity that is not divorced from critical or theoretical reflection.

Finally, many digital humanists find innovative ways to use new technologies to foster participatory learning and new forms of scholarly communication. Unlike traditional humanistic pedagogies, which are based on single-author, refereed publication—individual product not group process—participatory learning is a collaborative, interactive, and non-hierarchical version of authorship. The media theorist Henry Jenkins uses the term "spreadable media" to underscore the various ways of sharing knowledge and generating an "active commitment from the audience." Spreadable media empowers users to create new online and interconnected communities and to interact with others in forms (such as fandom or shared social, political, or intellectual interests) that they value (Jenkins 2009).

12.4 Case Study: The Futures Initiative at the Graduate Center, the City University of New York

There are many exciting, interdisciplinary teaching and research centers that explore the pedagogies, methodologies, and research questions that crystallize under the "big tent" of digital humanities. Here, we highlight just one example: the new Futures Initiative (http://futures.

commons.gc.cuny.edu/) at the Graduate Center at the City University of New York (CUNY). The Futures Initiative was established in 2014 in order to advance greater equity and innovation in higher education. More specifically, they advocate for collaborative, peer-driven classrooms as a catalyst for institutional, disciplinary, and social change. To achieve these goals, the Futures Initiative team embraces many of the central tenets of digital humanities: digital literacy, making, participatory learning, interdisciplinarity, and public engagement.

The inaugural course affiliated with the Futures Initiative, "Mapping the Futures of Higher Education," offered in spring 2015, was taught by Professors Cathy N. Davidson and former Graduate Center president and interim chancellor of the CUNY system, William P. Kelly. The course had two goals:

> to explore new methods of peer learning and teaching, interdisciplinary research collaborations, experiential learning, new digital tools, and public (online) contributions to knowledge . . . [and] consider the role of the university in society, especially public education in the U.S., in a stressed time where, nationally, we have seen declining support for public education, leading both to a student debt crisis and a professorial crisis of adjunct or contingent labor practices. (Davidson & Kelly 2014)

The course brought together graduate students across disciplines, who were simultaneously working toward advanced (primarily doctoral) degrees and teaching undergraduate classes across the CUNY campuses, from chemistry and computer science to art history and basic writing.

The student-led, student-designed course created a space in which graduate students could share ideas about digital technologies in the classroom, innovative ways to evaluate learning, the risks and rewards of student-centered pedagogy, and the real-life challenges and barriers faced by students beyond the classroom. Each week, the graduate students taught the course by assigning pedagogical readings and offering their classmates a range of new activities to try in their undergraduate classrooms. Each graduate student then designed an activity, tried it in their classrooms with their undergraduate students, and reported back on its effectiveness.

Digital literacy and critical, creative making were central to "Mapping the Futures of Higher Education." The Futures Initiative deputy director Katina Rogers worked with software developers to design a version of the Commons in a Box (CBox) platform, which allowed the graduate students to set up course websites and blogs to facilitate conversation among their students. While the majority of the students were initially technological novices (and some even skeptics), by the end of the course many saw how a digital platform like Cbox could help advance their pedagogical goals. In addition, the graduate students worked all semester toward their final project, the "CUNY Maps of New York" (http://futures.gc.cuny.edu/maps/), a series of visualizations that illustrate what public higher education offers a city (and vice versa). Instead of writing a traditional seminar paper, their task was to share what they had learned throughout the semester about innovative pedagogy. In order to complete this project, the graduate students learned to use software platforms and plugins, including Wordpress (a free Web software for creating blogs and websites), Maps Marker (a WordPress plugin for building customizable, layered maps), and Tiki-Toki (a Web-based software for designing interactive timelines). Through collaboration, and the public-facing affordances of these digital platforms, the graduate students designed creative ways to map and visualize learning as a resource for the city (Figure 12.1).

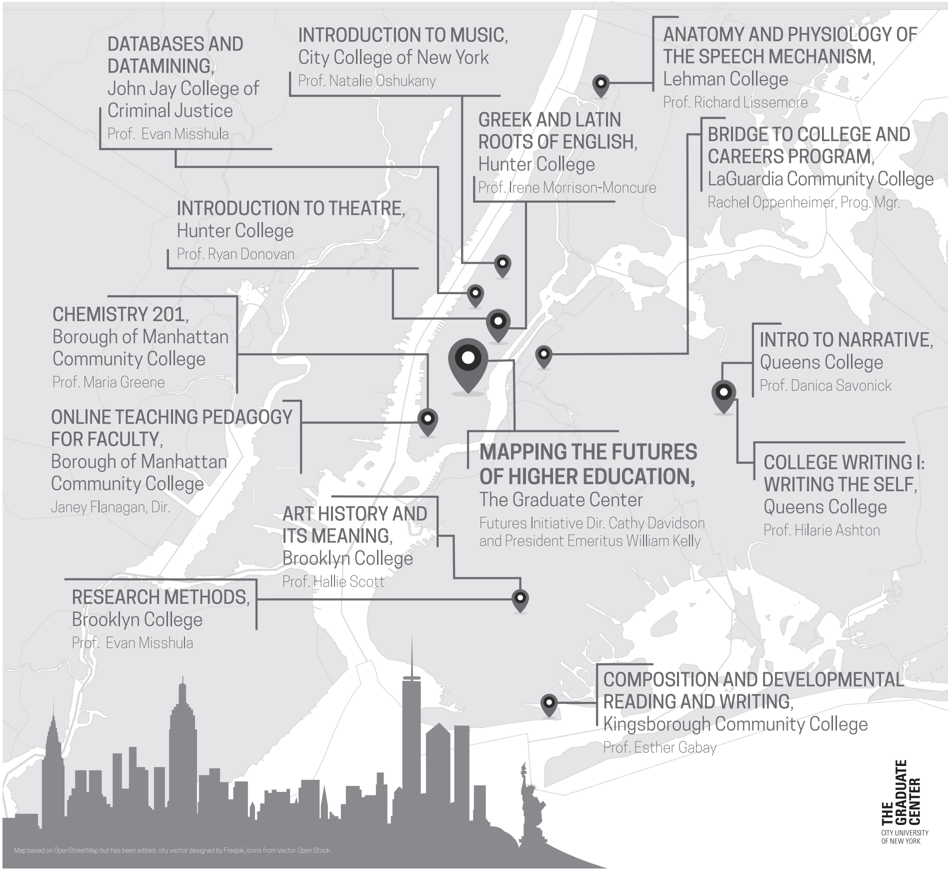

FIGURE 12.1 Visualization of "Mapping the Futures of Higher Education" by Kalle Westerling.

Visualization by Kalle Westerling.

While the graduate students' research interests varied widely, illustrating the entire spectrum of postsecondary education, they were brought together by their passion for integrating technology into teaching, and a shared understanding that educating undergraduates is not an ancillary obligation; it is foundational to the mission of higher education. They were digitally connected through the CBox platform, which hummed with activity all through the week in anticipation of each in-class seminar. It allowed the graduate students to easily share best teaching practices, and to facilitate interactions among their students whose colleges were spread out over Brooklyn, Queens, Manhattan, and the Bronx. Traditional seminar papers were replaced with weekly blogs, the majority of which were done publicly. The CBox platform allowed the class conversations and pedagogical innovations to have a multiplier effect: to ripple and reverberate across disciplinary and institutional divides.

"Mapping the Futures of Higher Education" brought the pedagogical insights of the digital humanities to graduate students teaching across disciplines and throughout New York City. Throughout the course, students developed teaching strategies that would help them prepare their students for the world we live in now: a world in which knowledge is crowdsourced, information is accessible at our fingertips, and skills like creativity, collaboration, and digital literacy are more valued than ever.

12.5 Digital Humanities, Interdisciplinary Programs, and Administrative Barriers: What Works, What Does Not

While "Mapping the Futures of Higher Education" was undoubtedly an interdisciplinary endeavor, it was organized and facilitated by two renowned humanists, both of whom had also spent extensive time as high-ranking administrators. They drew on these experiences in order to historicize contemporary learning conditions including curricular requirements, disciplinary debates, modes of assessment, and funding structures. Indeed, one cannot begin to conceptualize digital humanities—or any other epistemological intervention in academe—without considering the administrative protocols that can hinder or enable such projects.

The digital humanities often find institutional homes in and around English departments because of their shared disciplinary interests in cultural studies, textual analysis, the relationship between computers and composition, electronic archives, and the digitization of reading (Kirschenbaum 2012). However, exciting, interdisciplinary, and innovative teaching and research in emergent fields like the digital humanities often requires collaboration among a dizzying array of other fields that span not only departments but also the traditional administrative divisions of the university. "Divisions" are differently defined at different institutions and, as David Scholle (1995) has reminded us, inter- and intradisciplinary challenges are not only constructed differently depending on different institutional structures but also, in turn, structure the forms of intellectual work that can occur across and within departments and divisions. At most research universities, divisions serve to aggregate disciplines and departments as well as interdisciplinary programs into distinct and separate organizational units (sometimes called "silos"): the arts and humanities; the social sciences; the natural sciences and engineering; and then, in parallel and overlapping but distinctive relationship to the divisions, the various professional schools (such as law, medicine, business, divinity, and so forth). Colleges and universities have elaborate administrative and financial structures supporting these silos and individuals (typically, deans) whose responsibility it is to maintain the excellence, the mission, and the bottom line of their particular silo.

The divisional structure poses special obstacles to interdisciplinarity. To do their job, the digital humanities require, for example, partnerships, trades, and shared responsibility across the silos of departments and schools. Robust digital humanities programs require administrative oversight one level up, in the office of a provost (or whoever at a university serves as the chief academic officer presiding over all the educational units). Such issues as distribution of indirect-costs from federal grants across school budgets, infrastructure costs, reporting lines, accreditation, evaluation procedures, and disparate requirements for tenure and promotion in different schools or departments within schools all have an impact on the organization of such radically interdisciplinary and interdivisional programs and on the faculty they are able to attract.

The Futures Initiative has had to finesse all of these disciplinary obstacles, and across several campuses in the CUNY system at once. The cross-disciplinary, cross-campus, and citywide scope of the course, “Mapping the Futures of Higher Education,” required thousands of hours of faculty and administrative time to work through all of the details in compliance with the institutional and departmental structures of the different disciplines as well as within the cultural expectations of the disciplines. Sometimes the new interdisciplinary arrangement was seamless; other times it required a slow process of negotiation, renegotiation, and then trying yet again, often accepting compromise, partial solutions, and temporary or ad hoc arrangements.

Narratives of institutional success, failure, compromise, change, and complication are, of course, familiar to anyone pioneering interdisciplinary academic structures. The digital humanities are no exception. It is challenging to organize teams of digital humanists—oftentimes, their basic principles of interdisciplinary, project-based knowledge production challenge many existing administrative structures. It requires collaboration across areas of the university that rarely speak to one another and often do not even find themselves in the same college, never mind the same room.

One reason that it is becoming easier to make these interdisciplinary incursions into existing academic structures is that the digital humanities are proving to be robust. While academic positions may be dwindling in some fields, the number of offerings in the digital humanities continues to grow. Students are interested and enroll in the courses in good numbers, and granting agencies and other external funders look with excitement on the new developments coming out of this field.

Another reason for the success of this field is that, at a time when American universities are expanding their global reach, the digital humanities explore modes of cross-cultural communication, scholarly exchange, and public engagement. For example, the Hemispheric Institute, founded by scholars Diana Taylor, Zeca Ligiero, Javier Serna, and Luis Peirano, uses the Internet to make connections, trilingually, among scholars, artists, activists, and performers across the Americas. Their projects include an extensive digital archive of political performances from across the Americas, curated pedagogical modules for teaching students to engage with these materials, and multimedia casebooks or “web *cuadernos*” on particular topics related to politics and performance such as “Indigenous *Encuentros*,” “Holy Terrors: Latin American Women Perform,” and “Mapuche Campaign for Self-Representation” (Hemispheric Institute 2013). If the traditional humanities can sometimes seem Eurocentric and therefore provincial in the contemporary world, digital humanists have long grasped the international possibilities of both the technologies and understandings necessary to make a truly global, interconnected world work.

12.6 Conclusion

To return to Stuart Hall’s point about interdisciplinary fields emerging in specific historical moments, it is clear that digital technology is going to continue to transform our lives. This makes it important for humanists—who are, after all, trained in cultural interpretation and critique—to apply their methods of close reading, historical perspective, social engagement, ethical consideration, and linguistic attentiveness to new technologies. What is clear is that the Internet is not just a technology: It is a *changed environment*. Understanding that changed environment in all of its dimensions is one goal of digital humanities.

The potentials for abuse of new technology, as well as the potentials for positive transformation, loom so large that it requires scholars in many fields thinking together to understand the implications of our age. It also requires humanists moving out of their comfortable disciplinary niches to assay the interdisciplinary scope of technology's impact. The digital humanities require collaborative thinking from the development of new tools all the way through to the implementation stage, from ideas to application.

Radical transdomain interdisciplinarity across the humanities, arts, social and natural sciences, engineering, and technology requires translation of the most minute and the least examined disciplinary assumptions that we all hold (sometimes without knowing it) in order to communicate with those who share almost nothing in the way of training, expertise, skills, or knowledge. Such translation is worth it because it is the only way that we are able to answer a question or face a challenge that is shared across disciplinary divides. It is that shared commitment, in fact, that crosses the divides of practices, traditions, and deep affective relations to one's subject areas. These commitments are, on the deepest level, what bind us (in all senses) to traditional disciplines, even when we think we have migrated away from them.

Typically, when such collaboration happens, the result is, in Julie Klein's taxonomy, something closer to multidisciplinarity. Each person contributes, but there is no actual transformation. As Klein notes, "When integration and interaction become proactive, the line between *multidisciplinarity* and interdisciplinarity is crossed" (1996, p. 6). With digital learning, collaboration can lead to new questions, new challenges, and (as is appropriate for the field) even new objects of study. Many fields are customizing, repurposing, retooling, and redesigning their objects of study, and, in some instances, the definition of the field itself. In Klein's terms, that is not just interdisciplinary but transdisciplinary, with an emphasis on the "transcendent" qualities that inform the most basic assumptions that participants bring to the enterprise.

As many people have noted in regard to many fields (from music to science), new digital technologies and tremendously accelerated computational capacities are driving advances in knowledge as much as the other way around. This means that the digital humanities are also a driver of monumental and even foundational conceptual changes in many disciplines. Digital humanists are not only developing new areas for analysis by new computational tools but also, while developing such tools, expanding our understanding of the implications and consequences of their development. Finally, because *how one learns* underlies every part of a university, the digital humanities have the secondary consequence of pressing change in all of the component areas from which they draw and to which they contribute.

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CHAPTER 13

A FIELD OF ITS OWN

The Emergence of Science and Technology Studies

SHEILA JASANOFF

In 2001, science and technology studies (STS) made an appearance as a card-carrying field in the *International Encyclopedia of Social and Behavioral Sciences* or *IESBS* (Smelser & Baltes 2001). This validated years of effort by many scholars to establish the social studies of science and technology as a recognized, and recognizable, domain of intellectual activity. As a member of that network and as the editor of the *IESBS* section on STS, I was understandably elated, even though putting the section together entailed many difficult and unforeseen choices of what to include or exclude in defining the field.[1] Even then, STS was not counted as a discipline, a label reserved for fields with well-established, one-word names (e.g., anthropology, economics, history, law, philosophy), and for branches of psychology. Instead, STS was classified as an "intersecting field," a rubric shared with a cluster of relatively recent, amorphous, and ill-assorted domains of study such as genetics and society, gender studies, religious studies, and behavioral and cognitive neuroscience. Unlike media studies or public policy however, STS was not demoted to the status of "application." It took its place in the roster of the social sciences as a well-demarcated territory on the map of knowledge.

This review asks what major contributions STS has made to research and teaching, and what have been its principal successes and failures inside and outside academia. How does the future look for STS? Responses to these questions help shed light on the meanings and challenges of interdisciplinarity, illuminating the potential that spaces between disciplines offer for novel constellations of inquiry to enhance human self-awareness, social understanding, and public action. At the same time, the track record of STS shows how difficult it is to populate those in-between spaces with well-trained scholars, new curricular offerings, and long-term research programs. At the heart of the story are questions about the capacity of STS to overcome entrenched status differentials among disciplines, especially between the humanistic social sciences and the powerful enterprises of university-based science, medicine, and engineering.

[1] I had already coedited the second edition of the field's own handbook (Jasanoff et al. 1995), but inclusion in the *IESBS* meant more explicitly staking out a claim for STS in relation to other disciplines.

Jasanoff, S., *A Field of Its Own: The Emergence of Science and Technology Studies.* In: *The Oxford Handbook of Interdisciplinarity, Second Edition.* Edited by Robert Frodeman, Julie Thompson Klein, and Roberto C. S. Pacheco: Oxford University Press (2017). DOI 10.1093/oxfordhb/9780198733522.013.15

13.1 An Interdisciplinary History

At the risk of oversimplification, and of flattening important cross-cultural differences, STS can be seen as a merger of two broad streams of mid-twentieth-century scholarship.[2] One looks at the *nature* and *practices* of science and technology (S&T) as social institutions possessing distinctive normative commitments, structures, practices, and discourses that nevertheless change over time and vary across cultural contexts. The other is mainly concerned with the *impacts* and *control* of science, and even more of technology, with particular focus on the risks that S&T pose to human values such as health and safety, peace, security, privacy, community, democracy, development, and environmental sustainability. The consolidation of STS at the beginning of the twenty-first century is largely a consequence of these once-discrete lines of concern coming together around a shared core of theoretical orientations, research methods, texts, and topics, undergirded by new professional infrastructures (e.g., programs, departments, textbooks, journals, societies). Thus, STS is the product of decades of effort by people who perceived important gaps in the academic analysis of S&T, and who gradually, painstakingly, and with mixed success built institutional foundations to support the missing research and teaching.

The resulting field is interdisciplinary in a sense that can best be captured through a cartographic metaphor. Underlying the idea of interdisciplinarity are two ideal-typical maps of preexisting disciplines. In one, all the disciplines are tightly lined up, one against another, as in a map of the contiguous United States, with shared boundaries and no gaps between; in the other, as in a map of the Indonesian archipelago, the disciplines are idiosyncratically bounded islands, scattered across a sea of ignorance, with unexplored waters in between.[3] On the first map, a new "interdiscipline" comes into being principally through exchanges among scholars belonging to one or another established disciplinary community and trained in its forms of reasoning and research practices. On the second, an "*inter*discipline" is literally that—an autonomous formation situated among other disciplines. Such a field may arise in response to new concerns in society, such as the pervasive sense of uncertainty that propelled Ulrich Beck's *Risk Society* to unexpected popularity in the wake of the Chernobyl accident (Beck 1992). Exploration of novel topics, prompting theoretical and methodological innovation, can coalesce into a new culture of knowledge making with its own native habits of production and exchange. Science and technology studies looks more like the latter than

[2] The story told in this chapter is unavoidably US- and Euro-centric, given the author's experiences and knowledge limitations. However, STS is an increasingly international field, whose past, present, and future rest on global networks of scholarship and exchange. One way to strengthen the account offered here would be to trace parallel genealogies of the emergence of STS from other national and regional vantage points, particularly in emerging industrial societies. That is an impossible undertaking in a chapter of this scope. Yet, the coming together of those histories, and the resulting strands of theorizing and research, in the global academic marketplace will undoubtedly contribute to STS's future strength and liveliness.

[3] Note that the two alternatives captured by my cartographic metaphor correspond roughly to the categories of multidisciplinarity and transdisciplinarity presented in Klein's taxonomy in this volume. The taxonomic approach, however, does not problematize the taken-for-grantedness of disciplinary boundaries, nor emphasize their contingency or question their claims to coherence as I implicitly do in this chapter.

the former: less a program of interstate highway construction among existing states than an attempt to chart new territories among islands of disciplined thought in the high seas of the unknown.

13.1.1 The Nature and Practices of Science and Technology

From the interwar period to the start of the Cold War, sociologists and historians, and not infrequently scientists, engineers, and social activists, became interested in the relationship between scientific practice and its work products. Thomas Kuhn's hugely influential *The Structure of Scientific Revolutions* is a well-known example (Kuhn 1962). Kuhn's work helped turn scholarly attention away from the theoretical content and coherence of scientific claims to the social means of their production. His book helped crystallize a new approach to the history of science in which scientific facts were seen as products of scientists' communal knowledge-generating efforts, conditioned by specific contexts of discovery. This shift led to an effort by a group of mainly British scholars to probe how far questions about the nature of science once asked mainly by philosophers could be productively reframed as questions about how science works (Bloor 1976). Their inquiries produced a distinctive school of "sociology of scientific knowledge" (SSK)[4] located in centers for "science studies" at a number of UK universities, including Edinburgh and Bath, in the 1970s. The aim of SSK was more imperial than interdisciplinary: It was to render social what had previously been seen as mainly epistemic (how scientists think); it was to appropriate for the qualitative and interpretive social sciences what had once belonged to philosophy (by asking what scientists do, how they do it, and how their work achieves authority).

While SSK was emerging from struggles between philosophy and sociology of science, scholars from other backgrounds recognized the value of ethnographic methods for studying scientists at work. An early, influential exemplar of this approach was the 1979 book by Bruno Latour and Steve Woolgar, *Laboratory Life: The Social Construction of Scientific Facts*; the word "social" was dropped from the 1986 edition. In this and subsequent writing, Latour urged students of science to "follow the scientist" if they wished to understand how observations in the lab or the field turn into facts (Latour 1987). Participant-observation proved a useful tool for exploring the cultural dynamics of different scientific disciplines (physics, molecular biology, genomics, climate modeling) and organizations ("big science," university laboratories, interdisciplinary research centers). Latour, together with his colleague Michel Callon, a sociologist of technology and, later, the market in the Paris-based school of STS, also produced important works on the relations between the human and nonhuman or the social and material elements of S&T. Their "actor-network theory" (ANT), which urges symmetrical treatment of human and nonhuman agents, known as "actants," emerged as another salient direction in STS research. By highlighting the material elements

[4] SSK contrasted, in particular, with then dominant trends in US sociology of science, which concentrated more on the social organization and roles of scientists than on their specific knowledge-producing practices. American sociology of science was led by a number of distinguished practitioners, such as Robert K. Merton of Columbia, but their work increasingly diverged in aims and methods from the more epistemologically, metaphysically, and semiotically inclined European schools.

of knowledge networks, ANT foregrounded technology as an increasingly more significant object of STS study.

A third important research tradition looked at science and technology as distinctive cultural formations. Engaging anthropologists, feminists, postcolonial scholars, discourse analysts, and other theorists of language and power, this body of work crossed the line between the humanities and the social sciences, particularly in its preoccupation with the meanings people attach to the products of S&T. In works such as Donna Haraway's (1989) investigations of primatology or Evelyn Fox Keller's (1986) studies on gender and science, cultural studies of science and technology questioned how social power translates into scientific authority and vice versa. A flourishing body of scholarship emerged around medical S&T, focusing on such topics as reproductive medicine, patient activism, and hereditary disease; unlike classical studies of the physical sciences and technologies, these more human-centered investigations emphasized themes of identity and subjectivity, especially of those affected by disease classifications. More generally, an influx of research funds from the Human Genome Project spurred broad-based exploration of the ethical, legal, and social implications of genetics and genomics, contributing new normative dimensions to cultural studies of the life sciences and technologies. Less common but equally agenda-setting was work on the relations between science and other powerful institutions, such as law, politics, and religion; these works highlighted the impact of cultural norms of legitimacy and reasonableness on the production and reception of policy-relevant scientific facts (Jasanoff 1990, 2005).

13.1.2 The Invention of Technoscience

Unlike historians of science and of technology, who maintain separate identities through professional training and associations, STS scholars made a point of integrating their studies of scientific discovery with analyses of the technological systems that support or result from advances in science. The term "technoscience," widely used in STS research and the name of the newsletter issued by the Society for Social Studies of Science (4S), signals a deep commitment to the view that S&T are inextricably intertwined. STS scholarship asserts that technological innovation would not be possible without scientific problem-solving; in reverse, scientific discovery could not proceed without technologies to enable new experimental methods and approaches. Accordingly, in studying high-energy physics or molecular biology, bakelite or musical synthesizers, stem cells or Golden Rice, the Internet or the human genome, STS researchers pay particular attention to the interplay of ideas, instruments, and materials in the practices of the discoverers, inventors, and users of S&T. By using the term "technoscience," the field draws its own distinctive boundaries around the subject matter it investigates.

The third handbook of STS sponsored by the Society for Social Studies of Science, one of the field's major professional societies (Hackett et al. 2007; for an earlier survey of the field, see Jasanoff et al. 1995) is illustrative. The handbook's final section, headed "Emergent Technosciences," deals with systems that cross the lines between the cognitive and the material as well as the natural and the social. This section includes articles on genomics, medical biotechnologies, finance, environment, communications, and nanotechnology. All are areas in which scientific and technological breakthroughs are intimately connected, conform to no straightforward temporal or causal relationships, and depend on multifaceted engagement by actors ranging from individual discoverers, inventors, and entrepreneurs to expert communities, economic sponsors, policy makers, and consuming (or sometimes resisting) publics.

13.1.3 Impacts and Control of Science and Technology

The second major thrust within STS derives from scientists'—and increasingly citizens' and social movements'—concerns about the impacts of S&T developments on health, safety, and fundamental human values. The dropping of the atomic bombs on Hiroshima and Nagasaki in 1945 and the ensuing nuclear arms race between the United States and the former Soviet Union initiated a new politics of technological anxiety. Themes of scientists' complicity in war and violence, and technology's lack of democratic accountability, grew in prominence during the Vietnam War, which also helped link earlier worries about the ungovernability of science with nascent concerns about S&T's environmental implications. The marine biologist Rachel Carson's book *Silent Spring* (Carson 1962), an attack on indiscriminate chemical use widely credited with launching the modern US environmental movement, appeared in the same year as Kuhn's book on scientific revolutions. More recently, genetic, information, neuro-, and nanotechnologies, and their rapid convergence in areas such as synthetic biology, have aroused new fears about risks to individuals and society. Observers question whether the benefits of these promising developments might be offset by erosions of liberty, privacy, autonomy, equality, and other cherished liberal ideals. At the limit, questions have arisen about assaults on human nature itself, with the ascendance of the computer and associated forms of standardization and control into intimate bodily functions, social relationships, and autonomy of will and thought. Increasingly, too, the consequences of global imbalances in S&T innovation, and their implications for human rights and social justice, have emerged as centers of gravity for STS scholarship and cross-national collaboration.

In the late 1960s, several US universities, including Cornell, Harvard, MIT, Penn State, and Stanford, reacted to these developments by forming programs in "science, technology, and society" (also abbreviated as STS). Founded, and often led, by senior scientists or engineers—experienced in science advice and policy formation, these programs presumed that STS work had to be cross-disciplinary in the sense of highway-building described above, engaging natural scientists and engineers, as well as humanists, social scientists, and practitioners in law, business, and public policy. Preoccupied with social problem-solving, the founders of US STS programs presumed that good STS research demanded familiarity with the technical content of S&T. This meant in turn that early contributions to research and teaching were made by scientists (or ex-scientists) and engineers, or by teams that included technically trained researchers. Humanists and social scientists were tacitly assumed to have no significant independent insights into the functioning of S&T, although their participation was considered essential for illuminating the "soft," value-laden, societal dimensions of S&T. Cornell's STS program provides a small marker of these attitudes and assumptions. It was established in 1969 by a chemist (Franklin Long), a physicist (Raymond Bowers), a biologist (Richard D. O'Brien), and a philosopher of language and mathematics (Max Black).

The prominent role of scientists and engineers helped establish the credibility of STS research in its early years, but it also introduced several constraints: emphasis on empirical case studies rather than social theory; reaffirmation of scientists' necessarily partial perceptions about the cultures and practices of S&T; reliance on anecdotal practitioner narratives rather than systematic research to explain science-technology-society relationships; and acceptance of public "scientific illiteracy" as the favored explanation for popular concerns about S&T. The topics treated by first-generation STS scholars also reflected some of these limitations. Case studies of the public controversies of the day (airports, nuclear power, supersonic transport, vaccines, environmental pollution) took center stage, with results sometimes indistinguishable from robust journalism. More problematically, such research failed to win the interest of major scholars in established humanistic or social scientific disciplines, and many STS programs in the United States, such as Harvard's and Cornell's, either died a quiet death or substantially lost momentum by the mid-1970s.

One should note too that STS scholars in the 1970s drew on fairly conventional social theory to explain why science became political—for example, attributing technical controversies to differences in participants' taken-for-granted interests; hence they neither drew on nor contributed to seminal insights in other fields. At a time when many social sciences were turning to quantitative methods and rational choice theory, it was easy to dismiss qualitative, case-specific STS findings as merely anecdotal or subjective. Unlike the scholars preoccupied with the practices of scientists, however, researchers focusing on the impact and control of S&T were drawn from the first to issues of power and governance. Their work highlighted how dominant processes of technical decision-making tended to marginalize weaker social groups; neo-Marxist theorists tied these dynamics to class, capital, and hegemonic beliefs, whereas feminists argued that gendered power structures drove developments in S&T. In these respects, even first-generation STS research shared significant concerns with later sociocultural studies of S&T. Openings existed for a productive synthesis, which began in the United States in the late 1980s under the increasingly common rubric of "science and technology studies."

13.1.4 Common Ground

Convergence between the two major precursors of contemporary STS—work on the nature of scientific production and on the impacts of S&T—occurred on both intellectual and institutional levels. Maturing research programs brought scattered projects and practitioners into closer communion and helped define common theoretical approaches and topical interests. In brief, research on the nature of science became more concerned with how social understandings or arrangements are taken up into the production of knowledge and artifacts, while research on the impacts of S&T recognized that the interactions of science and society begin long before the material products of technology enter the market and affect lives. As a result, the power of S&T was no longer seen as wholly separable from other kinds of power. Nor were the formation and application of knowledge considered entirely distinct from their eventual uses and impacts. Thus, the ways in which science's epistemic authority interpenetrates other kinds of social and psychological authority emerged as a major thread in the field's evolving agenda of inquiry.

By the end of the 1990s, a new generation of STS scholars began examining issues such as the following: the nature of expertise in various historical periods and cultural settings; the resources used to forge agreement on "facts"; the relationship between scientific representations and wider visual culture; the disciplining effects of instruments, measuring techniques, and administrative routines; the use of nonhuman agents, including model lab organisms such as flies or mice, in the work of science; the methods of maintaining or challenging boundaries between scientific, technological, and other cultural practices; and the intermingling of expert and lay cultures around such issues as genetic disease. The field's long-standing concerns with fact, truth, and method did not vanish, but they "thickened" to include a new preoccupation with how novel ideas, entities, and belief systems appear and make their way in the world (and how old ones die out). More than simply accounting for "truth," STS became concerned with the social dimensions of the accreditation and diffusion of knowledge and its technological manifestations. There was also growing interest among STS scholars of all stripes in examining the relations between scientific and other modes of belief, expression, and power: law, literature, culture, religion, art. Science in non-Western contexts was a relatively late-blooming topic, but was included in the 1995 STS handbook and thereafter grew into a significant focus on global S&T.[5]

With all of these projects on the rise, older disciplinary divisions no longer made much sense within STS, particularly in the training of young scholars. For example, since the field's research questions centered on the nexus of knowledge and power, cutting across historical periods, budding STS scholars saw benefit from exposure to historiography as well as social theory, ethnography as well as metaphysics, and political as well as moral philosophy. The methods used by some of the best-known senior academics in the field were increasingly difficult to localize by discipline. Equally, the work they produced found its way across the field as a whole and into many neighboring disciplines. Science and technology studies books were reviewed in journals running from *Science* and *Nature* to the *New York Times Book Review* and the *Times Literary Supplement*, with the whole range of the field's professional journals between. The unifying feature in all cases was the *subject* of study, namely, human investments in science and technology.

While many STS researchers could still be characterized as mainly anthropologists, historians, or sociologists, it seemed increasingly more appropriate to distinguish them in relation to their research fields and theoretical commitments. By the early years of the new century, it became less common to find mature STS scholars who defined themselves in terms of a "pure" discipline (history, philosophy, sociology, anthropology, politics, economics) applied to a single science or technology (biology, physics, chemistry, engineering, medicine, risk analysis). Textbooks introducing students to STS reflected this cross-disciplinary synthesis, although, reflecting the authors' early disciplinary training, these works approached STS variously from more sociological (Collins & Pinch 1993), anthropological (Hess 1997), or philosophical (Cutcliffe 2000; Sismondo 2010) perspectives.

To be sure, there was never a complete integration of assumptions and methods across the spectrum of STS, any more than there is between subfields within most traditional disciplines. Specialties endure and thrive, as in any disciplinary context. For example, boundary-spanning subjects such as risk, scientific evidence, bioethics, or the public understanding of science figure more prominently in the work of STS scholars descended from the tradition

[5] Institutional changes supporting this expansion of the STS agenda include the establishment of the Japanese Society for Science and Technology Studies in 2001, the launch of the international journal *East Asian Science, Technology and Society* in 2007, and the formation of the STS-Africa Network in 2011.

of concern with the impacts of science and technology; by contrast, historically or philosophically trained STS researchers have tended to look more at the evolution and practices of disciplinary scientific knowledge and technological communities. By the same token, attention to visual representation and instrumentation, widespread in historical and cultural studies of science, is less common in the work of those with primary interests in the politics of S&T. Ethnographic approaches have been used more often to study lab cultures and patients' groups than, say, environmental controversies or legal proceedings. More generally, constructivist theories have made greater headway in contemporary than in historical studies of science and technology, possibly because historical methods are poorly adapted to observations of science in the making. Comparable differences of theory, method, research styles, and topical emphasis, however, may be encountered within the most securely established and coherent disciplines.

13.2 Academic Institutionalization

Despite its creativity and originality, the branch of STS concerned with the nature and practices of contemporary S&T was slow to gain a foothold in university structures. In part, this simply reflected the field's growing pains: At the turn of the twenty-first century, not many senior scholars of unquestioned eminence identified their careers unambiguously with STS. In part, too, the field suffered from the balkanization that sets in when resources are insufficient: Seeing little benefit from self-identification with STS, young scholars often reverted to better-recognized disciplinary affiliations, such as anthropology, history or sociology, or to topical subfields within STS for which there was current market demand, such as bioethics, environmental studies, science policy, or even nanotechnology and society. In turn, such moves hampered the recognition of commonalities that cut across the field, with negative consequences for graduate education, which thrives best in a stable environment of accredited teaching centers and steady job opportunities.

Non-negligibly as well, STS in the 1990s earned a reputation for relativism that evoked scorn from working scientists, other social scientists, and some university administrators. Labeled the "science wars," a subset of the culture wars then afflicting the universities, those exchanges called into question whether constructivist approaches fairly portray progress in science or advances in technology. Although difficult to document, worries about the field's intellectual soundness and descriptive accuracy, coming at a time when universities were becoming increasingly dependent on their links to science-based industries, may have inhibited the institutionalization of STS in the upper reaches of academia in several Western countries. The widely decried hostility toward science during the US presidency of George W. Bush, coupled with a growing perception that scientific progress and technological innovation are crucial for economic growth, may also have undermined institutional support for scholarship seen as questioning the authority of science.

Until the late 1980s, graduate studies of the nature and role of science and technology in US universities were mostly organized in one of the following ways: departments or programs in the history (and sometimes philosophy) of science and technology (HPST); programs (occasionally departments) in science, technology, and society (STS); and programs in science, technology, and public policy (STPP). These arrangements reflected a number of tacit intellectual boundaries. Historical and contemporary studies were thought to belong in separate compartments; even at the University of Pennsylvania, where history and sociology of science nominally resided in the same department, the focus remained on social histories of science and medicine. The frequent pairing of history with philosophy of science reflected a union of interests in these fields around the content of scientific ideas. This alliance worked well for "internalist" historians, but less well for those venturing into social and cultural history. Another implicit boundary sequestered studies of science, technology, and public policy within professional schools, as a supposedly "applied" field, away from the more "fundamental" humanities and social sciences (as at Harvard, Michigan, and Wisconsin). So conceived, STPP focused more on specific areas of scientific and technological practice than on broader ways of thinking about the nature of S&T. A few programs and departments did not respect these divisions, but they mostly existed at engineering colleges and technical universities, where they did not compete with traditional disciplines. Members of those programs, too, tended to define themselves as anthropologists, historians, sociologists, or political scientists rather than as representatives of an integrated field of STS.

Two external developments in the mid-1980s helped to partially remap these configurations. First, the processes of global academic exchange brought about closer contact between European and North American scholarship, narrowing the gap between research traditions on the two sides of the Atlantic. Bridges were built between the more structuralist and political approaches to studying S&T in the United States and constructivist and philosophical scholarship in Europe. Second, the US National Science Foundation (NSF) opened a nationwide competition to support interdisciplinary graduate training in STS. This initiative led to the founding of three successive programs in the early 1990s, at the University of California–San Diego (UCSD), Cornell University, and the University of Minnesota. The Cornell grant spurred the establishment in 1991 of a Department of Science and Technology Studies in the College of Arts and Sciences. Merging the earlier HPST and STS programs, the new department comprised about a dozen faculty members offering both undergraduate and graduate training in STS. By the late 1990s, all three NSF-supported programs were producing doctorates and postdoctoral trainees who entered the academic market and raised the profile of STS.

While such large-scale center awards ended after the first three, the NSF continued to support more modest, research-based graduate training in STS. A series of Small Grants for Training and Research (SGTRs) supported limited numbers of graduate students and postdocs to work on well-defined themes within the field. SGTR recipients in early years included Carnegie Mellon, Cornell, Harvard (JFK School), Minnesota, Oklahoma, and Rensselaer Polytechnic. In addition, the NSF supported conferences and workshops designed to promote curricular innovation and theoretical integration under particular thematic headings, such as diversity in science and engineering, or biology and the law. Targeted funding for looking at technology's social impacts and implications also became available under federally sponsored research programs such as the Human Genome Project and the National Nanotechnology Initiative; parallel initiatives emerged in Europe and (sometimes) East Asia, although with different funding models and implications for student training.

Unlike the earlier STS programs, the new STS maintained strength where it put down solid institutional roots and made gradual inroads elsewhere. Thus, the NSF-funded programs at Cornell, Minnesota, and UCSD added faculty strength over time and, in some cases, branched into new areas of research, such as genomics, information technologies, and nanotechnology. The STS program at MIT, which already controlled its own faculty lines, also grew during this period, partly by adopting a new doctoral program, although the STS faculty remained organized along mostly disciplinary lines with greatest strengths in history and anthropology. STS departments or programs at some prominent technical universities (e.g., Georgia Tech, Rensselaer Polytechnic, Virginia Polytechnic, University of Virginia School of Engineering and Applied Science) made additional professorial appointments. In the midwest, the University of Michigan appointed STS scholars in several departments and created an STS undergraduate certificate program. The University of Wisconsin, home to well-established history of science and history of medicine departments, appointed a cluster of STS scholars and established a graduate certificate program in STS. Similar developments occurred in the University of California system, especially at Berkeley, Davis, and Santa Cruz, during the early years of the twenty-first century. Rapid expansions in research and graduate training at Arizona State University included a build-up of STS scholars and the establishment in 2008 of a doctoral program in the human and social dimensions of science and technology.

Science and technology studies was recognized as a field of graduate training in a number of northern European countries (Netherlands, Scandinavia, Switzerland, United Kingdom) during the 1970s. Subsequently, from the turn of the century, the European Union began supporting a widening network of universities offering a standardized master's level curriculum in STS, administered through the University of Maastricht in the Netherlands in collaboration with the European Interuniversity Association on Society, Science and Technology. In the same period, the French government added a required component of history and philosophy of science to graduate training in S&T, while other state-funded initiatives looked to strengthen research and training in STS more broadly. Initiatives in Germany included most importantly the STS graduate programs at the University of Bielefeld, a preeminent center for interdisciplinary studies. When STS lost strength at Bielefeld through faculty attrition, research continued in smaller clusters funded by Germany's "excellence initiative," as well as programs initiated by institutions such as the Technical University of Munich. Several southern (and eventually eastern) European countries also built strength in STS during the 1990s, usually through professional societies and European research collaborations. Japan formed an STS network of its own in 1990, and by the late 1990s actively participated with China, South Korea, and Taiwan in an East Asian STS network served by its own specialist journal and professional meetings. From the mid-1990s the Chinese Academy of Social Sciences undertook a major effort to publish STS work, often with an emphasis on the impacts and social control of technology.

13.3 Research Frontiers

Interdisciplinary research is often driven by questions that demand input from more than one area of study. Policy research is a prime example: To know how best to control greenhouse emissions from automobiles, one needs to know something about the design of cars, the economics of innovation, the dynamics of the automobile market, the impact of incentives on consumer behavior, and the laws regulating air pollution at state and federal levels. No single field or person possesses all the necessary knowledge; collaboration among disciplinary frameworks and their distinctive knowledge systems—on the model of interstate highway construction—is therefore crucial. Significant developments in STS, however, were driven by questions of a different kind: those that one field sought to appropriate from others, and those that no field had thought to investigate before. In each case, the impetus was to view scientific and technological production as social domains deserving fine-grained study, and thus to bring the full-blown apparatus of social analysis, including interpretive methods, to elucidating those dynamics. The results, in cartographic terms, were consistent with the model of charting the unknown seas to discover new islands of insight and learning.

Published in 2007, the third edition of *The Handbook of Science and Technology Studies* ran to 1,080 pages, comprising 38 chapters organized under 5 topical headings (Hackett et al. 2007; for comparison, see also the second handbook edited by Jasanoff et al. 1995). The 2008 joint meeting of the European and American societies for STS showcased around a thousand presented papers; the 2010 Society for Social Studies of Science meeting, held in Tokyo, featured more than 200 sessions. Clearly, any attempt to characterize the research frontiers represented by all this activity risks simplification to the point of caricature. Nevertheless, some broad strokes may convey the unique nature of STS's interdisciplinarity.

Some of the earliest foundations for STS were laid, as we have seen, by sociologists and anthropologists who provided minute but eye-opening accounts of the scientific practices that lead to the creation of facts. The resulting genre of laboratory studies remains a staple of STS, but its focus has widened to include many more dimensions of practice than the moments of significant discovery or revolutionary change that concerned early historians of S&T. The conception of science itself expanded to accommodate wider domains of systematic knowledge production and technological uptake, from automobile engineering and weapons development to environmental and financial modeling, the creation of markets and fiscal instruments, and varied indicator systems, such as the metrics used to measure scientific productivity. A second direction was to investigate not just the leading figures associated with breakthroughs and prizes but also the invisible technicians, instrument-makers, nurses, counselors, forensic practitioners, and even patent writers without whose involvement scientific knowledge could not be produced or disseminated beyond the lab or the clinic. A third extension was to pay closer attention to the myriad nonhuman elements that play a part in the discovery process, from mice to microscopes to microarrays.

A more subtle shift occurred as researchers considered not only the production of new knowledge but also its circulation in society. A seminal history of experimental practices in Restoration England by Steven Shapin and Simon Schaffer (1985) called attention to the importance of credibility and witnessing in the spread of experimental science—themes that these and other authors developed in later work. While many STS researchers addressed reception and uptake within expert communities, subsequent work showed that broader social analysis was needed to understand the authority of science in the modern world. Thus, studies of the public understanding of science (Wynne 1995) and science used in public policy (Jasanoff 1990, 2005) followed science out of its contexts of production into contexts of interpretation and use, where science acquired substantial power to shape the directions of human advancement and well-being.

Questions of reception—whether inside or outside the circles of scientific practice—are intimately linked to an abiding STS concern with the relationship between science, power, and politics, especially in democratic societies. Although research in this area has shifted in focus and methodology over more than 40 years, it too provides powerful justification for the acknowledgment of STS as a distinct academic field. Salient insights include the following: Controversies are productive social moments, offering windows on the ambiguity of scientific observations and the possible existence of alternative interpretations; technological systems are agents of governance because, like laws and social norms, they both enable and constrain behavior; S&T policies, in both the public and private sector, build on tacit and inarticulate imaginations of what the public wants or needs; public participation and engagement are essential for ensuring that the imaginations of states and industries are held to critical scrutiny and democratic oversight. Some of these findings are now so taken for granted that they underwrite operational rules of citizen participation in most technologically advanced societies; others are inchoate and remain to be translated into political and administrative action. Science and technology studies scholars have become increasingly involved not only in generating knowledge about the relations between science and politics but also in the translation work needed to convert knowledge to action (Fisher 2011).[6]

13.4 Outlook: Barriers and Opportunities

Some 50 years into the life of a new field, and 15 years into a new century, STS remains weakly institutionalized in the upper reaches of global academia. Despite growing attention to the field's intellectual contributions, there are few full-fledged STS departments in the United States, even fewer in Europe, and barely any in Asia or Latin America. Departments, moreover, tend to cluster in engineering schools and, with few exceptions, have not taken hold in high-prestige research universities, where STS has to compete with long-established social sciences and humanities. Large hurdles remain. These are built into the political economy of the disciplines in contemporary higher education, as well as into STS's own contradictory self-understandings. Briefly, there are three challenges of disciplinarity and interdisciplinarity that STS will have to overcome before it can take its place as a necessary, indeed indispensable, component of higher education: establishing credible relations with its objects of study (S&T); defining its relations to other disciplines; and asserting a stronger sense of its own boundaries and mission. The good news is that STS has the resources to meet all three; the bad news is that STS scholars have not yet chosen as a community systematically to tackle any.

First, STS faces the not inconsiderable difficulties of "studying up": it presents a classic case of a less established, less accredited field commenting on ones that are far more securely established, generously endowed, and seen as conferring more obvious public benefits. It is well known that such power differentials affect the content and credibility of academic analysis. With respect to science and technology, in particular, practitioners are often skeptical that anyone not trained in a technical field could have legitimate things to say about that field's workings. Indeed, many of the earliest entrants into STS held postgraduate degrees in science or engineering before becoming professional observers of those fields. Physicists

[6] Warranting mention in this connection is the entire special issue of *Science and Engineering Ethics*, Vol. 17, No. 4 (2011), "Science and Technology in the Making: Observation and Engagement," edited by Stephanie Bird and Erik Fisher.

became historians of physics, while biologists took up the historical or sociological study of biology, and engineers became major contributors to the history of technology. Yet, the requirement that one must be formally qualified in a field in order to speak authoritatively about it not only restricts access but also narrows the analyst's capacity to ask probing questions; an insider perspective develops that neither accommodates nor grasps the benefits of the outsider's questioning gaze. A consequence of this attitude in early STS work was to pay disproportionate attention to the production of scientific knowledge in relation to understanding how scientific claims and practices circulate through and are incorporated into society. Only with the emergence of STS as a field of its own has this imbalance between production and reception gradually been righted.

Second, STS has to confront charges of redundancy. Science and technology studies claims special status as "the" field that observes and interprets the work of S&T, but this privileged position is by no means universally accepted. Indeed, the traditional social sciences and humanities at many universities are reluctant to concede any territory to an autonomous STS. Disciplinary scholars insist more or less openly that the map of existing disciplines is good enough to support any of the highways needed for traffic in STS. Thus, it is difficult to persuade a sociologist that STS is not synonymous with the sociology of science, or an anthropologist that anything more than ethnography is needed to study the cultures of science or technology. Accordingly, strict disciplinarians argue that there is little value to STS as sovereign academic currency. It unlocks no doors to new research questions or methods, let alone to successful professional careers. Would-be STS graduate students are often told that they would be better off with a degree in a recognized discipline, with a sideline in studying science or technology. These are, to some degree, self-serving assessments. Few of the disciplines named in the *IESBS* have recognized the study of science and technology as legitimate specialties within their own intellectual configurations. More usual is the reaction of a political scientist at a major research university who once told me, "My department would never hire someone in the politics of science." Regrettably, blocking appointments and degree programs in STS effectively dries up the pipeline of human resources dedicated to comprehensive studies of S&T. University administrators for their part can rarely be counted on to create new conditions of possibility. Faced with interdisciplinary boundary struggles and resource constraints, they are more likely to draw back from the hard work of adjudicating among competing claims, to the disadvantage of any new island in the academic high seas.

Third, many scholars who see themselves as members of the STS community are hesitant to support disciplining in either sense of that term: importing order and coherence into the delightfully unruly territory they came to know as STS in the 1970s; or constituting STS as what some dismissively called a "high-church," an elitist and exclusionary academic enclave that inhibits free thinking and creativity (see Fuller 1993). External funding initiatives, whether from governments or private donors and foundations, could overcome some of these hesitations, to the point of grounding new programs and reviving old ones (e.g., at Cornell, UCSD, and Wisconsin in the United States). Forging new transdisciplinary identities, however, demands an intensity of effort and engagement that seems unnecessary to academics whose own histories are discipline-based. Even the most secure STS programs in the United States and elsewhere have endured identity crises at some point in their development; at such times, moreover, new fields are substantially more likely than old ones to succumb to administrative pressures for efficiency and cost-cutting.

Fields demand organization for their survival and continuity, both to demarcate them from neighboring territories and to set up internal markers by which to measure such academically essential attributes as originality, quality, progress, and contributions to fundamental knowledge. Yet in a field's emergent, formative phase, attempts to develop a curriculum, create a canon, evaluate students and faculty for professional advancement, or even represent the field in an encyclopedia or handbook all arouse high tension and anxiety. Who will be brought in and celebrated; who will be left out? Many therefore prefer the quieter option, which is to retain STS as a loosely constructed society to which anyone with a passing interest can gain easy entry. This broad-church approach satisfies liberal academics' deep-seated desire for intellectual democracy, but it also gets in the way of critical stock-taking, meaningful theorizing, and methodological innovation—in short, of *disciplining*. In this respect, STS operates as its own most effective critic. It ratifies a status quo that militates against the field's maturation as a self-defining, self-governing area of inquiry.

13.5 Conclusion

The problem of interdisciplinarity is often posed as one of harmonization, or bringing disparate perspectives into alignment so that different discourses can speak productively with one another. Much as independent nation-states have trouble subordinating their divergent interests and political cultures to agreements on common problems, so the traditional disciplines encounter frictions in their efforts to focus on socially salient phenomena—from climate change to the roiling of global financial markets—that seem to demand investigation from multiple perspectives. How should number crunchers speak to qualitative analysts, or critical theorists engage with advocates of game theory and rational choice? How should inductive, evidence-based, and practice-oriented scholarship find common ground with principled approaches that draw authority from historical texts and frameworks that have little bearing on the issues of the present? Is integration possible and desirable, as in behavioral science or area studies (see Klein, this volume), or are exchange and bridge-building the only realistic alternatives? And who decides when and by what criteria participants in an interdisciplinary venture have made sufficient contributions to the purposes of the academy to merit their own charter of independence?

Science and technology studies has encountered all of these problems, and to some extent coped with them, but in a context that makes the field's challenges larger and more consequential than those of interdisciplinarity more generally. For what is at stake in the success of STS is the underlying self-understanding of the disciplines themselves as coherent and unified entities. By contesting such dominant understandings, as a field with epistemology as its primary focus *must* do, STS enters into troubled and uncertain territory. In the terms sketched here, the future of STS depends on redrawing the map of the disciplines to demonstrate that they are all islands of happenstance, with unmapped waters between; STS then can claim a space for itself as another fertile territory in these wide waters, offering resources for understanding some of humanity's most impressive accomplishments, but without threatening anything achieved, or yet to be achieved, in other quarters of the disciplinary archipelago. What is needed to make this case, first and foremost, is an abiding conviction on the part of STS-islanders that they have shared crafts and practices, and valuable goods to offer, in the ongoing enterprises of pedagogy and scholarship. There are major obstacles to achieving such agreement, both internal and external to the field. Equally, however, there are growing numbers of ambassadors abroad who confidently wear the badge of STS as their primary academic credential. The future of the field will depend on their intellectual ambition, rhetorical skills, and diplomatic acumen.

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CHAPTER 14

COGNITIVE SCIENCE

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Cognitive science is the interdisciplinary study of mind and intelligence, embracing psychology, neuroscience, linguistics, philosophy, anthropology, and computer modeling (artificial intelligence). It has many practical applications, including education, intelligent systems, human–machine interaction, design, management, and mental illness. The mind is far too complex to be understood using ideas and methods from only one discipline, so interdisciplinary collaboration is crucial for theoretical, experimental, and practical progress.

There are many reasons why a budding academic might want to avoid interdisciplinary research. It is difficult enough to acquire expertise in one field of research, let alone two or more. The time required to read the literature in a field outside your own main area can be hard to find, and the additional time investment to learn novel methods from another field can be huge. Moreover, the hiring and reward systems in academia still run strongly along disciplinary lines, so that work that draws on or contributes to other fields may not be fully valued in your own field. Interdisciplinary research may not be appreciated by narrow-minded colleagues. Some interdisciplinary projects have a bogus air about them, looking like they were designed more to bring in big research grants than to accomplish intellectual goals. The interdisciplinary scholar can look like a bit of dilettante, dabbling in multiple fields in order to avoid tackling the difficult problems in an established field. Grants for interdisciplinary research can be difficult to get, because most granting agencies are organized along disciplinary lines.

Despite these deterrents to interdisciplinary research, there are powerful intellectual reasons why work that oversteps the ossified boundaries of established fields can have great intellectual benefits. Such benefits are vividly apparent in the interdisciplinary field of cognitive science, which attempts to understand the mind by combining insights from the fields of psychology, philosophy, linguistics, neuroscience, anthropology, and artificial intelligence. After a brief review of the history of the field and its contributing disciplines, this chapter examines some of the main theoretical and experimental advances that cognitive science has accomplished over the past half-century, deriving lessons that might be useful for researchers in any emerging interdisciplinary area.

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14.1 History

Construed broadly, cognitive science is as old as philosophical reflections about the nature of mind, and so dates back at least to Plato and Aristotle. Philosophers such as Francis Bacon, John Locke, David Hume, Immanuel Kant, and John Stuart Mill generated ideas about the contents and processes of thinking. Experimental psychology originated in the late nineteenth century with the establishment of laboratories by Wilhelm Wundt, William James, and others.

Modern cognitive science began in the 1940s, when visionaries such as Alan Turing (1950), W. S. McCulloch (1965), Norbert Wiener (1961), and Donald Hebb (1949) began to apply emerging ideas about computing, engineering, and brain systems to develop new hypotheses about mental mechanisms. Previous mechanistic theories of mind, ranging from the atomism of Lucretius to the behaviorism of B. F. Skinner, were much too impoverished to explain the complexities of human thinking. But in the mid-1950s there emerged a panoply of powerful ideas about how mental processes could be understood by analogy to computational ones. The major contributors included the psychologist George Miller (1956), the linguist Noam Chomsky (1957), and researchers in the nascent field of artificial intelligence, including Herbert Simon, Allan Newell, Marvin Minsky, and John McCarthy (McCorduck 1979). The year 1956 was particularly notable, as it marked publication of Miller's famous paper on information processing, "The Magical Number 7 Plus or Minus 2," and the Dartmouth conference that initiated the field of artificial intelligence. The fundamental hypothesis of cognitive science, that thinking consists of computational procedures applied to mental representations, began to influence research in psychology and other fields.

The term "cognitive science" was only coined two decades later (Bobrow & Collins 1975). Events in the late 1970s included formation of the Cognitive Science Society, creation of the journal *Cognitive Science*, and establishment of cognitive science programs at many universities. Today, evidence that interdisciplinary research and teaching in cognitive science is thriving includes multiple journals, international societies with regular conferences, and active teaching and research programs in many universities and organizations around the world. For detailed treatments of the history of cognitive science see Gardner (1985), Thagard (1992, 2005b), and especially Boden (2006).

14.2 Patterns of Collaboration

The interdisciplinary structure of cognitive science is displayed in the hexagon in Figure 14.1, the original version of which appeared in a report for the Sloan Foundation in 1978 (Gardner 1985, p. 37). The 13 lines in the hexagon indicate the range of possible connections between the six main disciplines of cognitive science, but the links are misleading in several respects. First, the disciplines have been highly unequal participants in interdisciplinary research. For example, although anthropology has contributed some highly interesting work on mental representations and processes in non-Western cultures, most anthropologists have shown little interest in cognitive science. More significantly, some of the most widely read philosophical discussions of cognitive science have been highly critical of it, for example attacks

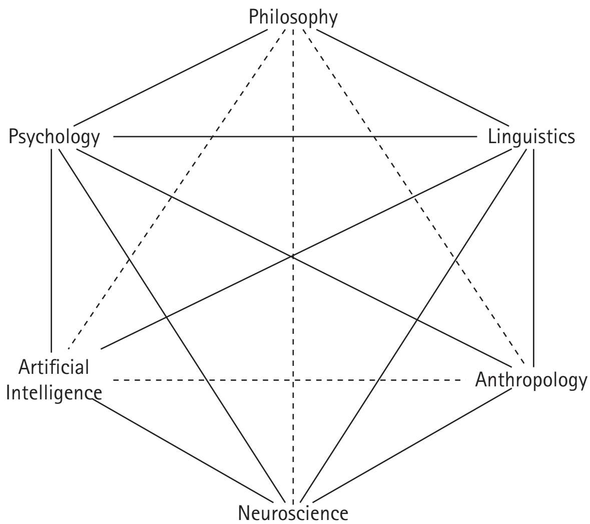

FIGURE 14.1 Connections among the cognitive sciences, based on Gardner 1985 (p. 37). Unbroken lines indicated strong interdisciplinary ties circa 1978, and broken lines indicate weak ones. The ties between philosophy and both neuroscience and artificial intelligence are much stronger today.

by Herbert Dreyfus (1979) and John Searle (1980) on the computational view of minds. The field of artificial intelligence has moved away from the interest in human thinking that inspired its early decades to a more engineering-oriented concern with the building of intelligent computers. In contrast, most cognitive psychology research is naturally dedicated to understanding the operation of human intelligence.

Second, the hexagon does not convey the historical fact that some combinations of the fields have been much more active than others and that levels of activity have varied over time. When cognitive science began officially in the 1970s, by far the most prominent kind of interdisciplinary collaboration occurred at the intersection of psychology and artificial intelligence, continuing a pattern established in the 1950s by pioneers such as Herbert Simon (1991). Psycholinguistics also flourished early on. Neuroscience became much more central starting in the 1980s and 1990s, with the increased sophistication of neurally inspired computational models and the development of brain-scanning technology that greatly expanded the possibilities for neuropsychological experiments. Philosophers' involvement in cognitive science has been highly variable, ranging from dismissal on the grounds that philosophy must transcend the merely empirical (Williamson 2007), to systematic reflection on controversial issues such as the extent to which knowledge is innate (Stainton 2006). Since the 1980s there has been much philosophical discussion of issues that arise in cognitive psychology and neuroscience (e.g., Bechtel 2008; Thagard 2007). Most strikingly, the applications of psychology and neuroscience to traditional philosophical problems in ethics and epistemology have become active enterprises (for example, Appiah 2008; Knobe & Nichols 2008; and Thagard 2010). For example, progress in neuroscience raises serious challenges to traditional ideas about free will and responsibility. In contrast, philosophers' interest in linguistics has waned, probably because language is no longer seen as so central to philosophy as it used to be; and work at the intersection of philosophy and anthropology has always been rare.

The third misleading feature of the hexagon is that the lines only indicate binary relations between disciplines, whereas some important developments have involved collaborations across several fields. For example, computational psycholinguistics draws on ideas from three disciplines to develop formal models of how minds use language. Current work in theoretical neuroscience combines study of brains with psychological and computational ideas. Recent work on emotion attempts to address philosophical issues about rationality by means of computational models that are psychological, neurological, and even sometimes social (Thagard 2006). In sum, although Figure 14.1 provides a useful diagram of possibilities for interdisciplinary connections, it does not display the shifting patterns of disciplinary involvement in such research.

There are at least three styles of interdisciplinary interconnection. The first is when an individual alone does research at the intersection of two or more disciplines. This requires the researcher to acquire mastery not only of the ideas but also of the methods of more than one field. For example, there are psychologists who have learned to do computational modeling, and a few philosophers who have learned to do experiments in psychology or neuroscience.

A second powerful kind of interdisciplinary interconnection involves collaboration, in which two or more individuals work together on a project combining their knowledge and skills in ways that require some mutual comprehension but not full duplication of abilities. This pattern of research has often been the most successful one in cognitive science, which has benefited from collaborations involving people whose original backgrounds combined, for example, psychology and artificial intelligence, psychology and neuroscience, and linguistics and anthropology.

The third style of interdisciplinary research does not require such collaboration or even individuals who have mastered more than one field. There has been much valuable work by more narrowly disciplinary researchers that draws on ideas from related fields. For example, Eleanor Rosch's influential work on concepts as prototypes was inspired in part by ideas of the philosopher Ludwig Wittgenstein (Rosch & Mervis 1975). Many articles published in the journal *Cognitive Science* are not internally interdisciplinary, for they lack any combination of methods. But most articles that appear there are intended to be of interdisciplinary interest in that they address concerns inspired by or relevant to work in various fields concerned with the nature of mind and intelligence. For example, an experimental paper on the nature of human concepts falls squarely within cognitive psychology, but should be relevant to philosophical, computational, neurological, linguistic, and cross-cultural issues about mental representations. This third style of interdisciplinary research requires less personal investment than the individual mastery and collaborative styles. But it usually presupposes at least some acquaintance with relevant literature in other fields.

In the introduction, I mentioned some of the impediments to interdisciplinary research, but have described how cognitive science has provided a strong example of a successful effort to combine insights and methods from at least six disciplines. Now I want to depict more fully what that success has consisted in, by discussing the theoretical and experimental benefits of being interdisciplinary.

14.3 Theoretical Benefits

A scholar has been defined as someone who knows more and more about less and less. Pursuing minutiae is often an effective strategy in academic research, since becoming an expert in some narrow niche is often a good way to publish and secure tenure. For the more intellectually ambitious, however, it is much more exciting to pursue theoretical ideas that are both important and novel. How can such creativity be achieved?

It helps, of course, to be a genius, with cognitive resources such as unusually powerful memory, imagery, or speed in connecting previously unrelated ideas or facts. But creativity is not only for the swift, because others of more modest intellectual capacities can still be creative by putting together ideas that have not been associated by other thinkers. Perhaps it takes a genius to work in a well-trodden area and manage to come up with something totally novel, but for the rest of us there is an easier road to creativity. Instead of focusing narrowly on one academic field, a researcher can cast a broader intellectual net and make new connections by tying together ideas from different disciplines. Cognitive science has thrived intellectually by making such creative theoretical connections.

In the mid-1950s, the dominant psychological theories especially in the United States were behaviorist, claiming that a scientific approach to the mind should restrict itself to considering how environmental stimuli are correlated with behavioral responses. Behaviorism was encountering difficulties in explaining the complex performance of rats, let alone humans, but theories are rarely rejected because of empirical problems alone. Rather, it is only when an alternative theory comes along with a new way of explaining recalcitrant data that a dominant theory comes strongly into question (Kuhn 1970; Thagard 1992). What happened around 1955 was that ideas from the rapidly emerging study of computers provided a new way to think about mental processes that was as rigorously mechanistic as behaviorism but possessed much more explanatory power.

A computer program consists of a set of structures, such as numbers, words, and lists, and a set of algorithms, which are mechanical procedures that operate on those structures. Those not familiar with computer programs can think of how people add up a list of numbers, where the structures are the numbers and the algorithm is the procedure for addition learned in elementary school. Or consider a recipe book, in which the recipe consists of a list of ingredients (the structures) to which people apply a set of procedures such as mixing and baking. Computer programs provide a highly suggestive analogy about how minds might work: mental representations may be like the structures used in computer programs, and mental procedures may be like the algorithms that make computers run. The strongest claim to consider is that thinking is not only like computing but in fact is a kind of computing (Thagard 2005b).

The analogy just described has been fertile in suggesting many new ideas about how representational structures and computational procedures might be responsible for mental processes such as perception, memory, learning, problem solving, language use, and so on. Many productive specific theories have been developed about how rules, concepts, images, and analogies might operate in the mind. This theoretical productivity could never have happened if psychologists had stuck with the intellectual resources of behaviorism. Instead, by importing ideas from the study of computers, it became possible to have creative new theories of mental functioning. Whereas behaviorism restricted itself to stimulus-response connections, cognitive science investigates how behavior and thought result from mental representations and computational procedures that integrate perceptual stimuli and produce responses based on complex inferences.

Another interdisciplinary source of ideas about how the mind works is the study of the brain. Some early ideas about how the mind works drew on neural mechanisms, but brain-style computing only took off in the 1980s through the development of an approach known as connectionism or parallel distributed processing. Brains operate differently than conventional computers. Neurons are slow, firing on average fewer than 100 times per second, but they perform powerful computations by virtue of the fact that that there are so many of them (around 100 billion) operating in parallel. In contrast, computer chips are very fast, with billions of cycles per second, but they usually operate serially, one step at a time. Today there is a flourishing field called theoretical neuroscience that develops new computational ideas about how brains support various kinds of thinking (Dayan & Abbott 2001).

Besides computer science and neuroscience, psychology has also been influenced by ideas from other fields, including philosophy and linguistics. Psychology is not just a recipient of theoretical ideas, but has also served as a donor. Psychology has contributed to the field of artificial intelligence, the branch of computer science and engineering that tries to build computers capable of some of the impressive feats of problem-solving and learning accomplished by people. For example, some expert systems—engineering projects to make computers capable of tasks such as medical diagnosis—have drawn on psychological ideas about mental representations such as rules, analogies, and neural networks. Philosophy of mind and cognitive anthropology have also been heavily influenced by developments in cognitive psychology. Oddly, cognitive science has had little influence on fields such as literary theory and history, which could greatly benefit from richer ideas about how minds find meaning and make decisions.

Many more specific examples could be given of the development of new theoretical ideas in cognitive science through interdisciplinary collaboration, but here are two illustrations. The study of analogy has blossomed since the 1980s as the result of theoretical ideas that have combined insights from philosophy, psychology, artificial intelligence, and neuroscience. The goal of trying to understand how minds can often so productively apply ideas from one domain to another was studied by philosophers such as Mary Hesse (1966), but was greatly fostered by the development of new psychological ideas about how minds can use representations of one problem to solve another. Psychologists such as Dedre Gentner and Keith Holyoak devised new ideas about how people use analogies, partly on the basis of their own experiments but also drawing heavily on computer models, including ones that employ artificial neural networks (e.g., Gentner 1983; Gentner et al. 2001; Holyoak & Thagard 1995).

Recent work on emotion has also been highly interdisciplinary, drawing on philosophical ideas about norms, psychological ideas about representations, and most recently neurological ideas about how brains process emotions (Thagard 2006; Thagard & Aubie 2008). The intellectual goal holding all this together is the attempt to build computational models of how the brain produces emotions and uses them in other cognitive processes. Like research on analogy, it is hard to imagine how theoretical progress on emotion could have proceeded without combining ideas from multiple fields of cognitive science.

14.4 Experimental Benefits

Like physics and biology, cognitive science is not a purely theoretical enterprise, but also requires experimental investigations that can be used to evaluate competing theories. Interdisciplinary collaboration has contributed to experimental work in psychology in two ways: through suggesting new kinds of experiments to test interesting theoretical ideas and through providing new measurement tools for performing experiments.

In the 1960s, the young field of cognitive psychology evolved by developing new kinds of experimental techniques. The growing availability of computers made it much easier to perform experiments that measured the reaction times of subjects performing complex tasks, and the resulting data were used to test the information-processing models of thinking suggested by the new computational theories of mind. The computational models of analogy generated new experimental work to test their predictions. Linguistics also provided new theoretical ideas through Chomsky's work on rules and representations, which inspired new kinds of experiments in psycholinguistics (Pinker 1994). Philosophical ideas have sometimes suggested psychological experiments, as in Rosch's experiments on prototypes. A huge line of experimental research in developmental psychology concerning children's ability to understand false beliefs originated with philosophical ideas about intention (Boden 2006, p. 488).

In recent years, experiments in cognitive psychology have been most influenced by developments in neuroscience. Ideas about how the brain works have suggested new experiments worth doing, but even more importantly neuroscience has provided a whole new set of tools for measuring mental activity. The 1980s saw the development of powerful machines for scanning brains using techniques such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET). It has become common for cognitive psychologists not only to measure the behavior of experimental subjects when they are performing various tasks but also to scan their brains while performance is taking place. Different scanning techniques provide different kinds of detail about the brain regions and temporal courses of neural operations. It is even possible to temporarily disrupt neural processing using transcranial magnetic stimulation. Information about neural processes is also sometimes obtainable by implanting electrodes deep in the brain to stimulate particular regions. Thus the field of cognitive psychology has been transformed in recent years by the development of new experimental techniques made possible by neuroscience.

Science is most powerful when theoretical ideas mesh with experimental ones, and such meshing is highly apparent in current attempts to use computational models of brain operations to explain the results of many different kinds of brain-scanning experiments. By combining ideas and techniques from psychology, computer science, and neuroscience, cognitive science is successfully pursuing fundamental questions about how the brain works. Answers to these questions are directly relevant to ancient philosophical questions about how minds know reality, make judgments about right and wrong, and appreciate the meaning of life. For example, Thagard (2014) uses psychological and neurological research about vital human needs to argue that the meaning of life is love, work, and play.

Other practical applications include the prospect of improving education by a deeper understanding of the neural mechanisms by which people learn (Posner & Rothbart 2007). The rapidly emerging interdisciplinary field of neuroeconomics is using new knowledge about how brains make decisions to identify the causes of good and bad decisions (Camerer et al. 2005). Similarly, political decisions such as voting can be illuminated by investigations in psychology and neuroscience (Westen 2007).

14.5 Lessons

The success and attractive prospects of cognitive science can be attributed to five factors: ideas, methods, people, places, and organizations (Thagard 2005a). It is only useful for people from different disciplines to try to collaborate if there are theoretically powerful ideas that cross disciplinary boundaries. For cognitive science, the main integrative ideas have been representation and computation, which can illuminate the nature of thinking in ways that are useful for all fields of cognitive science: psychology, neuroscience, artificial intelligence, philosophy, linguistics, and anthropology. A representation is a mental structure that can stand for things and events in the world, and inference is a computational mental process that transforms representations. There are other more specific ideas that find valuable applications in many fields, for example particular kinds of representations such as rules and concepts. For example, some psycholinguists hold that knowledge of language consists primarily of rules such as "To put an English verb in the past tense, add -ed." For cognitive scientists, a concept is not a word or an abstract entity, but a mental representation with complex internal structure (Murphy 2002).

In addition, successful interdisciplinary collaboration requires complementary methods. Cognitive science employs many different methods, including psychological experiments, neurological experiments, computer simulations, conceptual analysis, linguistic theorizing, and ethnography. Few people have the time and aptitude to master more than one or two of these methods, but cognitive science benefits from the ways in which methods can be combined to help develop and evaluate explanatory theories about how the mind works. For example, a theory about the nature of concepts can be evaluated on the basis of all of the following: psychological experiments about how people form new concepts; neurological experiments about multiple brain areas involved in the use of concepts; computer simulations of concept learning and application; philosophical reflection on how concepts attach to the world; linguistics studies of concepts in different languages; and ethnographic studies that compare concepts such as color across different cultures. The goal of cognitive science is to arrive at theories that are strongly supported by evidence acquired through all these methods.

The initiation and progress of an interdisciplinary enterprise requires the participation of extraordinary people with the energy and vision to combine the insights of multiple fields. The origins of cognitive science in the 1940s and 1950s benefited from the efforts of extraordinary intellectual talents such as Alan Turing, Herbert Simon, George Miller, Noam Chomsky, and Marvin Minsky. Each of these thinkers combined powerful theoretical ability with appreciation of the insights and methods provided by a variety of different fields. The development of cognitive science organizations in the late 1970s depended on the intellectual vision and organizational skills of another generation of interdisciplinary talents, including Allan Collins, Donald Norman, and Roger Schank. Today, cognitive science depends on a host of people who are active both intellectually and practically in organizations such as the Cognitive Science Society.

Ideas, methods, and people cannot operate in isolation from each other, and occasional conferences are not sufficient to bring about the theoretical and experimental benefits possible from interdisciplinary research. It is therefore important to have places where disciplines can come together on a much more regular basis, at universities or other research institutions. In the 1960s, the Center for Cognitive Studies at Harvard led by George Miller and Jerome Bruner brought together many of the early contributors to the interdisciplinary study of mind. Carnegie Mellon University also provided a lively center of activity because of the presence of Herbert Simon and Allen Newell. In the 1970s, other universities such as Yale, Pennsylvania, Berkeley, Michigan, and Edinburgh developed active cognitive science programs, and in the twenty-first century there are many places that play the crucial role of fostering such interdisciplinary work. Some do so by explicitly having cognitive science programs, but there are many other related enterprises with different names, such as the Harvard's Mind/Brain/Behavior initiative.

Finally, the successful pursuit of an interdisciplinary field is greatly helped by the development of organizations that foster communication of ideas and methods across fields. For cognitive science, the main organization is the Cognitive Science Society, which began in 1979, now complemented by smaller societies operating more locally in Europe and Asia. There also are more specific organizations operating at the intersection of particular pairs of fields, such the Society for Philosophy and Psychology, the Cognitive Neuroscience Society, and the International Conference on Cognitive Modeling. The Cognitive Science Society holds annual conferences that bring together people from many institutions and fields, although psychologists are by far the most heavily represented. The Cognitive Science Society publishes the journal *Cognitive Science* and the newer *Topics in Cognitive Science*, which are complemented by a host of other interdisciplinary journals as well as a huge range of periodicals in the various fields of cognitive science. Thus organizations such as societies and journals are an important part of the flourishing of an interdisciplinary field. Robert Goldstone and Loet Leydesdorff (2006) use citation patterns to show that *Cognitive Science* plays a unique bridging role in transferring information across psychology, computer science, neuroscience, and education. Interdisciplinarity can be measured not only by number of articles produced by multidisciplinary teams but also by the role that publications play in connecting fields, thereby merging perspectives, tools, and methods.

Like narrower fields, interdisciplinary ventures are far from static, but benefit from changes in ideas, methods, people, places, and organizations. Much cognitive science work has shifted dramatically in recent years toward neuroscience, as many researchers see the study of the brain as providing much of the most currently exciting work on cognition. But not all psychologists, philosophers, and other practitioners share this view, which is just as well. The last thing needed by an interdisciplinary field, or any particular discipline for that matter, is a monolithic approach that narrows down to only a small set of ideas or methods. On the other hand, advances in theoretical neuroscience are beginning to suggest the possibility of a unified, brain-based theory of mind that extends to even the most challenging problems of the mind including creativity and consciousness (Eliasmith 2013; Thagard & Stewart 2011, 2014).

In contrast, the full benefits of interdisciplinarity require integration, interaction, and blending of ideas and methods, not their mere juxtaposing and sequencing as found in multidisciplinarity (Klein 2010). Cognitive science is sufficiently mature to have its own textbooks, but some are still structured sequentially, separately describing the approaches taken by philosophy, psychology, neuroscience, linguistics, and artificial intelligence (Friedenberg & Silverman 2011; Sobel 2001). In contrast, Thagard (2005b) and Bermudez (2014) discuss issues about mental representation and processing in an integrated manner that intertwines issues and contributions from different disciplines. Cognitive science is proving to be highly relevant to understanding other fields as well, including natural science (Thagard 2012), social science (Sun 2012), and the nature of interdisciplinary collaboration (Derry et al. 2005).

14.6 New Interdisciplinary Directions

In the early decades of cognitive science, from the 1950s to the 1970s, the field was largely concerned with forging connections among psychology, linguistics, and computer modeling. But in the past two decades, neuroscience has become increasingly relevant, not only to cognitive psychology but also to other areas including developmental, social, clinical, and educational psychology. At the same time, cognitive and social psychologists have paid increasing attention to cultural dimensions of thought, identifying important differences between thinking in the West and the rest of the world (e.g., Nisbett 2003). How can cognitive science progress by integrating what is increasingly known about the mind with new insights about the brain and culture?

Reductionist and antireductionist answers to this question are equally inept. Science cannot simply reduce culture to mind by explaining all social phenomena as resulting from individual psychology, because what goes on in individual minds is heavily influenced by the groups and norms within which minds operate. Nor can science simply reduce mind to brain, because the psychological functions and representations that people use are important for understanding what brains are doing. On the other hand, the antireductionist view that culture can be mind-blind and that psychology can be brain-blind are at odds with the enormous amount of evidence about interlevel connections. People interact with other people partly because of how they think about each other, and psychological structures such as concepts are increasingly open to neural explanations (e.g., Blouw 2016).

An alternative to both reductionist and antireductionist approaches is *multilevelism*, which investigates interactions among mechanisms at all relevant levels, including social, psychological, neural, and molecular systems (Thagard 2014). Explanation is not just bottom-up, from molecular to social, but sometimes also top-down: Social interactions such as one person complimenting or insulting another can have molecular effects such as changes in activities of dopamine, oxytocin, and cortisol. I predict that cognitive science will continue to thrive by tracing out these interdependencies among mechanisms at multiple levels.

Obviously this kind of integration will require even more intense interdisciplinary collaboration than has already occurred. No one person has all the expertise to span the full range of mechanisms, so future progress must benefit from enhanced involvement of molecular neuroscientists and social scientists in the traditional cognitive science concerns with the mental operations of thought and intelligence.

Collaboration is itself a process that needs to be understood at multiple levels. It is by definition a social process requiring interactions of two or more people, but it is also a psychological process requiring collaborators to think about a joint project and each other. Such thinking can now be plausibly connected with neural processes responsible for the concepts, rules, and conscious experiences that people operate with in groups. Emotion is also a huge part of collaboration, because working together depends on shared feelings such as excitement, trust, liking, and respect. The neural mechanisms of emotion are increasingly becoming understood, involving both interactions among brain areas such as the amygdala and insula and a chemical soup of important molecules such as dopamine and serotonin. Collaborators need to share values about their aims and methods, where values are emotional attitudes toward goals, rules, and concepts. Hence interdisciplinary collaboration will be indispensable for developing a richer understanding of how collaboration works through multilevel mechanisms.

14.7 Conclusion

This chapter has tried to show how the intellectual benefits of interdisciplinary research can dramatically outweigh the personal and social difficulties of operating in more than one field. Cognitive science provides an excellent illustration of the theoretical and experimental advantages of leaping beyond the confines of particular disciplines. The project of trying to understand the nature of mind is inherently interdisciplinary, requiring the ideas and methods of many different fields. There is still a place for researchers who prefer to restrict themselves to a narrow set of intellectual tools, but progress, especially of the most dramatic sort, requires the mingling of concepts, hypotheses, and methodologies from multiple disciplines. For theoretical, experimental, and practical progress, the separate disciplines that study the mind need to be interdependent, relying on each other for ideas and methods that complement their own. The human brain is so astonishingly complex that we should expect not decades but centuries of collaborative investigations in cognitive science.

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CHAPTER 15

MEDIA AND COMMUNICATION

ADAM BRIGGLE AND CLIFFORD G. CHRISTIANS

Language is commonly singled out as the essence of humanity (Cassirer 1946). Human beings are cocreators, because they give names to the plants and animals. They invent symbols to represent things in their world, which allows them to share the contents of their minds with one another. Thus, as linguistic creatures, humans are also inherently social, because they inhabit a shared symbolic order made possible by their powers of representation and communication. And because of this pervasive character of communication in the development of the human species, media and communication studies have not been contained in an explicit discipline, with its own subject matter. Interdisciplinarity has been essential for understanding it.

As core features of humanity, communication and media clearly predate academic disciplines. They are in this sense nondisciplinary. Yet, they have for centuries been the subject of inquiry by those concerned to understand and improve human correspondence. Since the early twentieth century, such studies of media and communication have proliferated. In the process, they have adopted nearly all of the forms of interdisciplinarity identified in the taxonomy provided by Julie Thompson Klein (this volume). The "bridging" and "restructuring" of knowledge communities to form new interdisciplinary domains of "communication studies" and "media studies" has been a particularly important development in this regard.

This chapter surveys the historical development and present form of multi-, inter-, and transdisciplinary studies of media and communication. It begins with a brief historical sketch of media and communication in order to indicate the kinds of phenomena motivating the studies. This sketch indicates that the four primary drivers of interdisciplinarity are present in this field. Media and communication are (1) inherently complex, (2) raise questions that are not confined to a single discipline, (3) pose societal problems that transcend the academy, and (4) are tightly linked to new technologies. Indeed, media and communication studies are motivated in large part by the complex questions and social changes brought about by new technologies.

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15.1 A Brief Historical Sketch of Media and Communication

For millennia, the oral medium was the sole form of communication, and techniques such as chanting were crafted for memorizing the essential stories of a people. Though epics could be told, the ephemeral nature of the oral medium established a natural governor on the production of knowledge. The inventions of the alphabet and of writing heralded a seismic shift in both human consciousness and social order (Ong 1982). Though writing made systematic inquiry and knowledge production possible, Socrates famously reacted to it with skepticism. Not only does the written transmission of knowledge betray a softness of mind (as one no longer has to rely solely on memory) but also it exposes one's most serious commitments to attack and degrading treatment while one is not there to defend them.

Subsequent innovations slowly prepared the way toward a modern world drowning in technological media and suffused with knowledge about media and communication—knowledge that is itself communicated, conveyed, and shaped by various media. These innovations include the index, punctuation, and other twelfth-century developments that lifted the "text" from the page, transforming reading from a communal mumbling to a silent, solitary affair (Illich 1993). Gutenberg's mid-fifteenth-century printing press is often cited as the most important watershed in the development of media. Movable type revolutionized European culture (by standardizing expression), politics (by broadening access to ideas and fostering nationalism), and religion (by making the Bible widely available, thereby upsetting the Church's monopoly).

It also eventually redefined the university. By 1800, printed books had become so numerous as to trigger fears about information overload and epistemic authority. The modern research university took shape in this context as the gatekeeper of legitimate knowledge and as the institution that generates authoritative knowledge as well as the individuals (academics) capable of extending and certifying new knowledge (see Wellmon 2013).

Electrification brought about the next major wave of change. This was primarily a shift toward broadcast media (waves encoded as transmission signals) as opposed to the mass production and circulation of physical artifacts (e.g., newspaper copies). But it also heralds the birth of film as it progressed beyond the daguerreotype and other early photograph technologies of the mid-nineteenth century. The beginning of this era can be symbolically dated on May 24, 1844, when the American inventor Samuel Morse first publicly demonstrated his electrical telegraph by sending a message from Washington, DC, to Baltimore that read, "What hath God wrought." Wireless telegraphy, or radio, soon followed with the 1896 construction of the first radio station on the Isle of Wight, UK, by the Italian inventor Guglielmo Marconi. The broadcasting of images through television first occurred in the early twentieth century, and in the years after World War II television sets became common household items.

At this time, "the media" became an established singular collective term referring to (1) the institutions and organizations in which people work with communication media (the press, cinema, broadcasting, publishing, etc.), (2) the cultural products of those institutions (genres of news, movies, radio and television programs, etc.), and (3) the material forms of media culture (newspapers, books, broadcasting towers, radio sets, films, studios, tapes, discs, etc.).

The arrival of the digital computer in the mid-twentieth century and later development of the Internet are widely credited as enabling the latest wave of change in media and communication. The shift here is from broadcast to network communication—arguably implying a shift from state control and masses to democratization and individuality. Digitality (the conversion of input data into discrete abstract symbols such as numbers) is a distinguishing characteristic of "new media" (Lister et al. 2003). Other distinguishing features include interactivity (active involvement and many-to-many communication as opposed to the passive consumption of the one-to-many broadcast media), hypertext (texts that link to other texts), dispersal (the decentralization of the production and distribution of media), and virtuality (in a strong sense as immersion or in a weaker sense as the cyberspace where participants in online communication feel themselves to be, including virtual worlds such as Second Life). Nowadays, it's not unusual for a newspaper picture to become an Internet meme or reworked as a digital impressionist or renaissance painting.

New media have also developed a further stage, often signified by the term "Web 2.0," which is characterized by enhanced social networking affordances and user-generated content delivery systems such as Facebook, reddit, YouTube, and Twitter. The latest revolution may be precipitated by the increase of mobile media such as cellular phones and iPods. Internet and television are also both merging and competing in complex ways with the advent of Roku, Apple TV, and other devices that can stream Internet channels such as NetFlix and Amazon onto TV screens. Developments in the near future may include the rise of wearable (and perhaps implantable) multimedia technologies that serve as cameras, phones, entertainment systems, and even meta-information devices for accessing and displaying information about anything encountered in one's environment (e.g., Google glasses). And artifacts—from products at a store to home appliances—may soon be connected in a communication network or an "Internet of things" (e.g., a refrigerator linked to a car capable of updating the driver on his or her milk supply before driving home from work). Another potentially revolutionary change is germinating with regard to user interfaces and the shift away from keypads toward natural gestures and perhaps even toward direct brain–computer interfaces. Children born on the crest of this accelerating wave of change, as "digital natives," are thrown into a world so pervaded by media that it is now known as the "Information Age" (Castells 1996).

Scholarly reflection on these developments is motivated by the increasingly profound implications of media in modern society. For example, media are making good on the popular image of a "global village," by intertwining the cultural, political, and economic fates of more and more people. Life via the Internet poses questions about personal identity, as people come to develop their sense of self in cyberspace, sometimes through the use of "avatars" or digital representations of people. The pervasive matrix of information and communication technologies now aids cognition to such an extent that it could be seen as an extension of the human mind beyond the confines of the skull. Other questions pertain to the quality of online communities, relationships, and education. Websites such as Wikipedia and WebMD muddy the categories of "expert" and "lay," while cultures suffused with screens and images confront questions about the meaning and relative value of reality and virtuality. Media of all sorts continue to be implicated in the fate of democracies around the world, entangled in thorny issues about censorship and legal jurisdictions. The "old" media suffer under the influence of new technology, posing questions about the future of journalism and the academy. For these and other reasons, media and communication studies have grown into a thriving and bewildering constellation of academic study.

15.2 Studies of Media and Communication: An Overview

Media and communication studies have drawn conceptual distinctions, formed methodologies and theories, hewn specialized discourses, coalesced communities of experts, created journals, awarded degrees, and become housed in institutions. They have at times developed within existing academic disciplines. At other times they have created their own disciplinary trappings or remained more nebulous in terms of disciplinary identity. And all of this is currently taking place in a context where new media are challenging many of these traditional academic endeavors by changing the way in which knowledge is produced, disseminated, and consumed.

Attempts at understanding communication have roots in the study of rhetoric, the art of oratory and persuasion, in ancient Greece and Rome. They branch upward through the medieval university and its *trivium* of logic, grammar, and rhetoric—the arts of thinking, inventing, and combining symbols to express thought, and communicating from one mind to another. The modern research university with its emphases on specialization and knowledge production has scattered and multiplied academic inquiry. The profusion of academic studies has also been fueled by the increasing diversity and importance of media in modern society. The resulting cornucopia of titles, programs, methods, and theories mirrors the jumbled labyrinth of the contemporary media technologies and cultures under consideration.

It is possible, however, to discern two main streams of academic study of media and communication, one social scientific and one humanistic. The first stream dates back to World War I, fueled by the problem of war propaganda and by radio technology that linked nations into mass media markets for the first time. Scholars in sociology, psychology, journalism, and political science began researching such developments, using the methodologies of their disciplines. Charles Horton Cooley, Walter Lippmann, and John Dewey were influential, because they all gave communication a central role in the attempt to understand social relations. In terms of Klein's taxonomy, this stream has adopted several identities. Especially in its early stages, it was predominantly a multidisciplinary juxtaposition where the disciplines retained their original identity. Yet it has increasingly featured versions of composite, methodological, and theoretical interdisciplinarity where integration occurs around a common problem and via conceptual frameworks, organizational principles, and methods.

The second stream comprises contributions from philosophers, historians, cultural anthropologists, cultural theorists, and scholars of art, literature, and film. Its origins are diverse and thus more difficult to pinpoint, although critical theory and poststructuralism are two major sources of much present-day humanistic study of communication and media. More concretely, in 1947, Wilbur Schramm, the "father of communication studies," founded the Institute for Communications Research at the University of Illinois at Urbana-Champaign. Holding a PhD in literature, he argued that communication theory will emerge out of language and linguistics, and established appointments in these areas. This stream can be roughly distinguished from the social science stream by its tendency toward critical interdisciplinarity and transdisciplinarity. Broad interdisciplinarity between these streams—let alone with the natural sciences or engineering—remains rare.

Insofar as they remain elements of existing disciplines, studies of media and communication do not acquire their own disciplinary identity. Students use established methods and theories and receive traditional degrees in philosophy, sociology, economics, and so forth, although with a dissertation topic focused on media and communication. This situation characterized communications studies at Columbia University. Through the Bureau of Applied Social Research at Columbia, Paul F. Lazarsfeld and others produced work that was highly influential in shaping the field. Yet while this work began in 1944, Columbia did not create a degree-granting graduate program in communications until the 1990s. Prior to then, communication studies fell under the umbrella of sociology.

In a dialectic familiar to students of interdisciplinarity (see Krohn, this volume), many forays into interdisciplinary media studies have been driven back into disciplinarity. Or as Klein notes, today's interdiscipline is tomorrow's discipline. This is caused by the "need for manageable objects and presentable results" within a reference community. Indeed, it is caused by the academy's need for reference communities to define the nature and judge the quality of scholarship and to perpetuate themselves by initiating students and obtaining financial and institutional support. Furthermore, the diversity of communication and media phenomena is also partly responsible for the fracturing of inquiry. The appearance of new media and new social landscapes calls for and creates ample opportunities to fashion the new theories, concepts, and methods that become the intellectual lifeblood of institutionalized disciplinary communities (McQuail 2003).

These epistemological and institutional requirements have caused the current abundance of university degree-awarding programs operating under a variety of titles and housing scholars publishing in a growing array of specialized journals. A sampling of the dozens of journals supporting this field of inquiry includes *Journal of Communication, Communication Theory, Human Communication Research, Critical Studies in Media Communication, Media, Culture & Society*, and *Feminist Media Studies*. Of course, the boundaries of this field are shifting and porous, and could be drawn more widely to include such journals as *Ethics and Information Technology* and *Journalism Studies*.

A sampling of some common university programs shows them grouped under such terms as "communications," "communication studies," "rhetorical studies," "communication science," "media studies," "mass communication," and "media ecology." Many of these programs self-identify as multi- or interdisciplinary because they juxtapose or integrate traditional disciplines. Some programs claim to be transdisciplinary, because they frame research questions and practices around real-world problems and coalesce around conceptual frameworks that transcend disciplinary worldviews. Yet, they are also disciplines in their own respect, because they sustain and perpetuate specialized communities of discourse (via majors and advanced degrees) around a shared set of problems, theories, methods, and/or concepts. As one way to indicate the disciplinization of this field, when Schramm established the first PhD in communications in 1947 at the University of Illinois at Urbana-Champaign, all faculty members held their PhDs in the established disciplines. Today faculty members of most of these degree-granting programs are recipients of doctorates from communication programs.

15.3 History of Mass Communications Research

Wireless broadcasting achieved technical excellence during World War I and swept rapidly through society as peace returned and military need subsided. The war symbolized the late-modern breakdown of traditional society and the emergence of not just mass media but also "mass society," including the mass production of transportation, goods, and education. Formal studies of mass media originated in the same postwar period as a central part of attempts to understand the massification of society. Many such attempts shared the idea that the masses, as formed by the disintegration of traditional society, were in need of mechanisms of incorporation to ensure social integration.

The history of mass media research could be told through a variety of narratives, including (1) disputes about goals, (2) incremental progress, (3) revolutionary change, and (4) disagreements about methods. This section briefly glosses each narrative. The take-home message is that these disputes, advances, changes, and disagreements create the various fault lines in the intellectual subsurface underlying the current panoply of departments and programs. That is, much of the institutional diversity in terms of (inter)disciplinary identities stems from the different positions staked within these narratives.

First, a basic divide in media and communication studies exists between the goals of serving mass media and critiquing it—or between what Klein identifies as instrumental and critical interdisciplinarity. Understanding media could be considered an independent goal, but often understanding is sought as a means to improved service or criticism. Of course, these goals are often reconciled, as both service and critique can lead to reform. Radio advertising, one of the original loci of mass media research, illustrates this overly simplistic but instructive dichotomy. In the 1920s, radio became a promoter's dream. Pepsodent sponsored *Amos and Andy*, one of the first radio comedy serials, and its sales increased by 70% in the first year. A host of today's prominent products achieved their recognition initially from the newly formed networks: Bayer, Goodrich, Wheaties, Pepsi-Cola, Bulova, Texaco, and more. In fact, early radio history could be written around combinations of program and brand name: Lucky Strike Orchestra, Eveready Hour, Voice of Firestone, Ipana Troubadours, A & P Gypsies, and Sieberling Singers.

In order to secure more such advertising success, official market research received abundant commercial funding. Such instrumental interdisciplinary research has allowed media messages to be delivered with more substantial impact. This is attributable to increased understanding of the significance of audience demographics (the age, gender, etc., of those tuned in to a given media outlet) for optimizing exposure to advertising and other content. It is also a result of the stipulation of differences among the media—especially their varying technological affordances. This is a clear example of research serving media. Yet commercial radio also became a site of critical interdisciplinarity. For example, Theodor Adorno and Max Horkheimer coined the term "culture industry," arguing that popular culture is akin to the factory production of standardized goods. Like political propaganda, this culture industry manipulates the masses into docility and passive consumption of easy pleasures. It creates the false needs satisfied by capitalism and threatens the true needs of freedom, creativity, and flourishing.

Second, the history of broadcast media research could be told in terms of linear progress. In several cases, media and communication studies have advanced knowledge by progressing in the manner commonly thought typical of science—theories or models are put forward, tested, and either tentatively accepted or rejected. For example, in the 1940s many researchers drew from the pioneering work of Harold Lasswell on propaganda to develop the hypodermic needle or magic bullet model of communication (Lasswell & Casey 1946). This model (a variant of the then predominant stimulus–response model) holds that mass media have a direct, uniform, and immediate impact on their audience. The mass hysteria caused by the 1938 broadcast of *The War of the Worlds* was cited as evidence for this model. But Lazarsfeld and others would go on to use this incident and other empirical evidence to challenge the model. Their studies demonstrated that broadcast media typically have selective and diverse impacts on people, depending on their beliefs and on contextual factors. Building from such studies, they offered the two-step flow model, with its greater emphasis on human agency, as an alternative.

Third, the history of mass media research could also be told as one of major conceptual rifts that resemble what Thomas Kuhn (1962) called "paradigm shifts" rather than stepwise linear progress. The most important paradigm shift occurred in the 1960s and 1970s as a transition from content to form. Prior to this time, studies tended to conceptualize media as tools for the transmission of content, with an emphasis on the nature of the content or message. For example, the earliest studies of political communication conceived of media as a vehicle for either education or propaganda. Concerns were raised by the pervasiveness of propaganda in totalitarian governments and its success in undermining critical thinking by the public. In 1937, an interdisciplinary group of US scholars founded the Institute for Propaganda Analysis with the goals of studying illegitimate manipulation, fostering critical thought, and contributing to intelligent engagement with mass media. In place of propaganda, early Marxist critiques conceptualized mass media as a vehicle for the transmission and reproduction of ideology, hegemony, or class domination. Whether propaganda or ideology, the emphasis was on the content of the messages rather than the structure of the medium.

By contrast, the French Marxist Louis Althusser initiated a "paradigm earthquake," by arguing that ideology should be understood as the structure or form of mass media, not just its content (Holmes 2005). For Althusser, ideology is not just found in the ever-shifting content of the messages absorbed by "given" or preexisting individuals. Rather, "ideology-in-general" constitutes individuals as subjects—it is the very condition by which an individual comes to have a representation of self and world. This subjectivity is created by the communication process itself. Thus, the kind of selfhood that emerges and the world it takes as reality depend on the structure or form of the communication.

The profound implication is that media do not deliver a representation (either neutral or distorted) of reality. Rather, they create reality. This "revolution," in Kuhn's terms, resonated widely. It can be seen, for example, in the thesis put forward both by the cultural critic Jean Baudrillard (1997) and the Heideggerian philosopher Albert Borgmann (1999) that simulacra have come to precede, determine, and crowd out the real. It is also apparent in the work of Marxist theorist Guy Debord (1977) and others advancing various spectacle or ritualistic theories of mass media. Debord argued that mass media create a certain field of visibility by concentrating the attention of the many on a particular event or representation. When this image is repeated, in time it begins to take on a life of its own—it becomes a spectacle—and that to which it refers becomes secondary and may even disappear from view.

This paradigm shift toward form or structure was also advanced, and even foreshadowed, by the two main "medium theorists," Marshall McLuhan (1962) and Harold Innis (1964). McLuhan differed from the spectacle and ideology views by rejecting their homogeneous picture of media and culture in favor of an account of the distinct specificities of different media corresponding to different modes of perception. Yet he shared their emphasis on form rather than content: "the medium is the message." Innis similarly analyzed how power gathers around different media structures, which has influenced later work on new media.

Finally, the story of broadcast media could be told in terms of debates about methods. For example, Lazarsfeld et al. (1944) transferred empirical and inductive methods from the study of radio advertising to the analysis of the 1940 presidential election. Their work suffered somewhat because they assumed that promoting candidates and selling soap were methodological equivalents. And although Lazarsfeld used sample surveys innovatively, his inductivism could not ultimately specify causal relations. It proved impossible to move beyond the correlation of two factors to demonstrate a causal relationship—an issue that has long haunted research on the impacts of media on society, from pornography to violence in computer games and movies. As one report on obscenity and pornography noted: "The research evidence is of the kind in which science follows in the wake of common sense" (Barnes 1971, p. xiii).

Carl Hovland, a psychologist working at Yale in the 1950s, produced some of communications' most suggestive studies (Hovland et al. 1953). These included the first report of the "sleeper effect"—when a highly persuasive message paired with a discounting cue causes the individual to be more persuaded (rather than less) over time. Leon Festinger also adopted the experimental method, but with less emphasis on exact precision and verification of causal relations. Specifically, his "dissonance theory" described communication effects in terms of desirable psychological states. Experiments statistically measure attitudes before and after some persuasive message under the basic presumption that humans need equilibrium, and beliefs change only to alleviate inconsistency.

As an alternative to laboratories, Norbert Wiener (1948) and Ross Ashby (1963) developed cybernetics as a formalist, mathematically based approach to the study of communication. Cybernetics is an instance of what Klein calls generalizing interdisciplinarity, because it applies a single theoretical perspective to a wide range of disciplines. This influenced Claude Shannon and Warren Weaver's *Mathematical Theory of Communication* (1949), which laid out the basic elements of communication as an information source, a transmitter, a channel or medium, a receiver, and a destination. It also developed the concept of a bit as a unit of information. This laid the foundations for information theory, becoming the basis for digital communications technology and the birth of networked or new media.

15.4 Networked Communications Research

The explosive growth of the Internet and network (as opposed to broadcast) communication in the 1990s has generated scholarship on a second or new media age (Hassan & Thomas 2006). Many of its foundational tropes—social disintegration, the virtual replacing the real, individuality, disembodiment, realignment of political power and economic order—were foreshadowed by science fiction works such as *Neuromancer* (Gibson 1986) and *Snow Crash*

(Stephenson 1992) and portrayed in films such as *The Matrix* (1999). Here too both social science and humanities streams are discernable, though with considerable overlap. Another set of distinctions is helpful for indicating some important topographic contours, including: (1) the relationship between old and new media; (2) utopias and dystopias; (3) computer-mediated communication; and (4) cyberculture.

First, early scholarship on new media placed strong emphasis on its distinguishing features. The old media architecture is one of central media producers transmitting content to an undifferentiated mass. The individual looks to the central media source to acquire cultural identity, not "sideways" at others in the crowd. By contrast, the new media architecture breaks down the walls separating individuals. They look at one another for a sense of self and belonging. This is why Mark Poster (1995) sets "interactivity" at the core of new media. Placing such stress on the revolutionary differences of new media fostered a widely held thesis that the new would quickly displace the old (Manovich 2002). The contraction or demise of newspaper publishers has lent some support to this thesis.

Yet newspapers have also adopted online publishing, featuring new forms of articles and advertisements. This kind of development has led some to argue that the picture is far more complex. David Holmes (2005), for example, questioned the historical distinction between the first and second media ages. He argued that the way in which individuals connect with the different media forms is interdependent—network communication becomes meaningful because of broadcast and broadcast becomes meaningful in the context of network. Jay Bolter and Richard Grusin (1999) similarly coined the term "remediation" to argue that newer forms of media have always refashioned older forms. A simple example of this is the way in which YouTube videos often remix popular television shows. The hit US comedy television show *The Colbert Report* even responded to such creations, prompting yet more online videos. Some describe such phenomena as the "convergence" of media functions and industries (Van Dijk 1999). The lesson seems to be that new media offer different possibilities for connectedness and creativity, but some of these engage and reshape old media rather than simply eclipse them.

Second, the view that digital, interactive media marked a revolution in communication was often wed to a utopian ideal. One expression of this ideal was the 1994 manifesto titled *Cyberspace and the American dream: A Magna Carta for the Knowledge Age* (Dyson et al. 1994). Langdon Winner (1997) extracted its core tenets as deterministic but positive technological change, radical individualism, free-market capitalism, and a rebirth of the public sphere and participatory democracy. Overcoming the passivity and homogeneity of the broadcast architecture means emancipation, enfranchisement, and creativity—indeed, individuals are free to experiment with identity in radically new ways (Turkle 1995). No longer does the mass media industry determine cultural or individual consciousness. Furthermore, an interactive media renews community by strengthening the bonds connecting people to their world.

As is often the case with emerging technologies, there are dystopian visions contrasting with the utopian ones. A primary motif here is the impoverishment that results when virtual and mediated experiences displace real and direct experiences. Hubert Dreyfus (2001), for example, argued that distance learning is a poor substitute for classroom education and more generally that lives increasingly spent online lack the defining commitments that sustain meaning and community. Cass Sunstein (2001) deflated claims about cyberdemocracies, by arguing that cyberspace is far more a private than a public space. It allows those online to see, hear, and read only what they like. This egocentrism is not only narcissistic, but weakens the exchange of ideas necessary for democracies. Nicholas Carr (2008) argued that the Internet diminishes cognitive capacities by fostering a staccato style of reading and thinking. The interpretive ability to make imaginative mental connections and relate new information to one's biography remains largely disengaged online. Other dystopian themes center on increased risks of identity theft, cyberstalking, an acceleration of the pace of life, and the threats to privacy posed by surveillance and data mining.

A third important story about new media is the growth of social scientific and psychological studies of computer-mediated communication (CMC) (Joinson 2003; Thurlow et al. 2004). Research in CMC examines the social and psychological dimensions of communication through two or more networked computers in formats ranging from e-mail to instant messaging to social networking sites and virtual worlds. Examples include research on identity construction online and behavioral changes under conditions of anonymity. Researchers often compare CMC to face-to-face relating. The umbrella term of CMC has created new communities of academic discourse via such outlets as the *Journal of Computer-Mediated Communication* and *Cyberpsychology.* The CMC literature can be mapped onto the utopia–dystopia landscape, especially regarding disputes about whether online communication is better or worse than offline forms. But by and large it strives for value neutrality and empiricism. Furthermore, this literature tends to adopt a narrower focus on individual interactions rather than the overall contexts by which those interactions form a meaningful whole.

Fourth, and by contrast, "cyberculture" has become a term of art in the humanities to draw attention to the ways in which media are shaping entire value systems, basic concepts, and patterns of life (see Davidson & Savonick, this volume). Culture, communication, and media are tightly interlinked (Langer 1977; Carey 1988). Cultures are interconnections of symbolic forms, those fundamental units of meaning are expressed in words, gestures, and graphics. Realities called cultures are inherited and built from symbols that shape action, identity, thoughts, and sentiment. Communication, therefore, is the creative process of building and reaffirming cultures through symbolic action. Although not identical to what they symbolize, symbols participate in their meaning and power; they share the significance of that to which they point.

The concept of cyberculture intrinsically links such humanistic theories of culture with technical concepts from computer science, robotics, artificial intelligence, and genetics. It has thus become the site of both interdisciplinary collaboration—including wide interdisciplinarity across the humanities, engineering, and sciences—and turf wars as various traditions and disciplines seek to make claims to a superior understanding of the unprecedented mixture of artifacts and ideas that characterize our times. Cyberculture, far more than CMC, maps onto the utopia–dystopia dialectic, because it conjures forth fundamental reflection on culture, technology, and nature—including how these basic categories are blurring through such phenomena as androids, cyborgs, and virtual ski slopes. By blurring these categories, cyberculture theorists tend to adopt a nonlinear sense of causality—things do not determine ideas nor do ideas determine things, but they are coconstitutive.

This means that the traditional humanist views of agency as solely the preserve of human beings and the human agent as separable from culture and technology are called into question. Thus, semiotics (the study of signs, symbols, and the construction of meaning) is an important wellspring for cyberculture studies, but it is often modified such that nonhumans become actors rather than just signs. Furthermore, semiotics traditionally maintains a narrow definition of culture as the products of the arts and language. Though this definition long dominated communication studies, cyberculture expands it by including the physical, technological media as intrinsic to culture. Culture is not just the content conveyed by media, but the structures and forms of media technologies and the other artifacts in which they are embedded and systems with which they are networked.

15.5 Conclusion

As the diversity of narratives and concepts in these histories would suggest, there is substantial disagreement and turmoil in the current study of media and communication. For example, the standard textbook on approaches to mass communication study (Severin & Tankard 2000) added critical theory and cultural studies to its overview in its fifth edition. But only, the authors note, because "they have become popular with scholars. Nevertheless, we remain committed to the scientific approach, with its emphasis on observation, evidence, logic and hypothesis testing" (p. xv). Most research funding still supports studies that measure observable behavior, finding in such results the statistical precision desired by private and public benefactors.

The current aim of the scientific approach is to develop more elaborate and finely tuned procedures, more complex multivariate scales, faster computer banks, and longer-range experiments, trusting that greater development of method will eliminate previous weaknesses, confusions, and uncertainties. Severin and Tankard (2000) summarize this scientific trajectory in terms of the incremental progress narrative:

> Communication researchers have not yet come up with a unified theory that will explain the effects of mass communication. Instead, we have a number of theories, each attempting to explain some particular aspect of mass communication. As communication research advances, perhaps we shall see several of these mini-theories combined into one overall theory of mass communication effects. Or, perhaps some of these theories will not survive the test of empirical research and will be winnowed out, while others survive. (p. 286)

The scientific trajectory in communication studies is currently bolstered by the surge of new forms of physical, computer, and biological sciences as well as new technical capacities. Indeed, this trend is toward communication studies as a form of "big science." Media and communication studies find themselves in the current transdisciplinary trend line toward the unification of knowledge. Some see this unification in terms of the cognitive and natural sciences swallowing social scientific and humanistic approaches. Communication and media studies, then, would become "scientistic," implying the importation of natural scientific methods for the study of social and cultural phenomena:

> Scientific advances, particularly in neurobiology, genetics, and neuropsychology, are encouraging researchers to consider re-theorizing "cultural" problems to take the new knowledge generated by science into consideration. Added to this, the achievement of the technical capacity to process large and complex data fields, a feature of the computerized knowledge environment, now suggests that alternative methods and approaches for the study of cultural phenomena may be possible. In other words, some research that we previously believed could only be solved by cultural approaches may be recast as questions for science and scientific inquiry. (Nightingale 2003, p. 361)

Yet this trajectory is not likely to yield that magical universal theory or homogenize the current diversity in the topography of media and communications studies. Rather, this infusion of natural, cognitive, computer, and physical sciences will most probably map onto existing landscapes and create ever more niches. This trend has occurred before—for example, in the fact that sociobiology became just another approach to human social life rather than a grand consilience marking the demise of approaches rooted in the humanities or social sciences. Indeed, this seems inevitable given that the mechanistic tropes central to the natural sciences are incapable of accounting for the spontaneities of the human life-world.

Joseph Klapper (1965), a proponent of scientific rigor in communication studies, regretted that after years at the "inexhaustible fount of variables," systematic description and prediction "becomes the more distant as it is the more vigorously pursued" (p. 316). The Enlightenment dream of mirroring nature would mean that at some point we could close the book of knowledge, having adequately transcribed reality. But the pursuit of knowledge is "inexhaustible"—especially in an information society where everyone is a publisher. The only governors on its growth are external and relatively contingent—the availability of funding and the interests of citizens, politicians, provosts, and CEOs.

Thus, there are contrary reactions to the growing confusion about the nature of communication and media studies. Some desire multidisciplinary juxtapositions to address narrowly defined academic questions. Others want interdisciplinary integrations to unify knowledge. And still others seek a transdisciplinary transcendence of academic disciplines in order to either serve or critique society. The danger of the transdisciplinary path is that in seeking to become relevant, media and communication studies will lose the disciplinary trappings that ensure academic viability. Yet as the academy continues to evolve under the influence of new media, it may be that transdisciplinary structures of knowledge production become more stable than the traditional disciplinary forms. In many respects, the future of media and communication research depends on how the phenomena under study will impact those very studies.

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CHAPTER 16

SITUATING FEMINIST STUDIES

ELLEN MESSER-DAVIDOW

Is feminist studies a disciplinary or interdisciplinary knowledge field, a one-sector or cross-sector formation, a scholarly or social-change project? The answers to these questions depend on location, location, location.

In this chapter I compare feminist studies in the United States and India, countries where the fields emerged from women's activism during the same decades but came to manifest significant differences in the ways knowledge is institutionalized, produced, and circulated. These differences, I argue, resulted from the host country's demographics, languages, economics, politics, cultures, religions, and uneven effects of the coalescing global order.

16.1 United States

In this section, I argue that the expansive infrastructure of US higher education both enabled the rapid growth of feminist studies and formatted what had begin as a social-change project as an academic interdiscipline.

16.1.1 Emergence

In the United States feminist studies emerged from 1960s movements with long histories of waves, strands, and networks. The knowledge and skills that women acquired during the nineteenth and twentieth century struggles for suffrage, birth control, and equal rights were transmitted to the Second Wave's liberal strand, activated in the 1960s when the Women's Bureau of the Labor Department, the President's Commission on the Status of Women, and the state commissions on women grew frustrated with the Equal Employment Opportunity Commission for failing to enforce nondiscrimination laws. Liberal feminists founded the National Organization for Women (1966), Federally Employed Women (1968), National Association for the Repeal of Abortion Laws (1969), and National Women's Political Caucus (1971).

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Meanwhile, alienated by movement sexism, Civil Rights and New Left women organized such leftist groups as New York Radical Women (1967), Bread and Roses (1968), Redstockings (1969), and Chicago Women's Liberation (1969). A few of these women led consciousness-raising (CR) meetings that borrowed techniques from the Mississippi Summer Freedom Schools (1964), the Maoist practice of "speaking bitterness," and Paulo Freire's *Pedagogy of the Oppressed* (English trans. 1970). Quickly spreading across the country, CR groups gave women a safe place to share experiences, map the contours of patriarchy, and change their lives. By then the Second Wave had a reticulated structure, its strands intertwining at protests, conferences, bookstores, and rape-crisis centers (Mueller 1994; Rosen 2000).

In 1968 radical academics founded the New University Conference; targeting disciplinary associations, they formed caucuses, demanded governance reform, and organized scholarly sessions. Feminist toeholds in the associations—along with feminist conferences at the University of Pittsburgh in 1971 and at Rutgers University in 1973—became platforms for disseminating feminist scholarship and studies of the status of academic women (Messer-Davidow 2002, pp. 87–115).

16.1.2 Institutionalization

From 1968 to 1970, feminists taught two-dozen women's studies courses on a half-dozen campuses. Their materials consisted of dusty library books about women, movement position papers, and such now-iconic works as Simone de Beauvoir's *The Second Sex* (English trans. 1953), Eleanor Flexner's *Century of Struggle* (1959), and Juliet Mitchell's *The Longest Revolution* (1966). Then in 1970 KNOW Press, obscurely housed in a Pittsburgh garage, duplicated a dozen course syllabi on unbound pages, avidly circulated hand to hand. Together with conferences, the *Female Studies* series, consisting of five volumes issued by KNOW Press and five more by The Feminist Press, fueled the exponential growth of the field. By 1974 feminists were teaching 2,500 courses, administering nearly 100 women's studies programs, and publishing in new feminist journals. Ten years later the field had a cross-hatched academic form: Its research and teaching were facilitated by an infrastructure of 500 women's studies programs, the National Women's Studies Association (1977), the National Council for Research on Women (1982), and feminist publications and by insertion into disciplinary apparatuses (Messer-Davidow 2002, pp. 84–86, 129–165).

Although we lack an exact inventory today, available information suggests that the United States has over 680 women's studies programs (Korenman 2015): 92 offer PhD degrees, 7 offer joint JD and women's studies degrees, 35 offer MA degrees, 74 offer graduate certificates, and all offer undergraduate majors or minors (Smith College Study 2015). We can see the field's structure by scanning the journal listings in *Feminist Periodicals*. It is both a free-standing interdiscipline (e.g., *Signs, Feminist Studies*) with transdisciplinary components (e.g., *Feminist Theory*) and numerous subfields embedded in disciplines (e.g., *Tulsa Studies in Women's Literature, Feminist Economics*), professional fields (e.g., *Feminist Criminology, Yale Journal of Law and Feminism*), interdisciplinary studies (e.g., *Journal of Lesbian Studies, Feminist Media Studies*), and topical fields (e.g., *Journal of Women & Aging*) (Gender and Women's Studies Librarian's Office 2014).

This cross-hatched institutionalization stoked feminist research and teaching, but at a cost. The institutional-disciplinary order, as Timothy Lenoir reminds us, is a dynamic system "for assembling, channeling, and replicating the social and technical practices essential to the functioning of the [academic] political economy and the system of power relations that actualize it" (p. 72). Although academic legitimation required feminist studies to comply with the norms for faculty performance in research, teaching, and service, today some still argue that the field "boasts a legacy of activist scholarship" (Orr 2011, p. 9). However, teaching literature on feminist activism is not the same as teaching activist skills, nor can feminist scholarship fuel activism if it lacks bridging structures to extra-academic arenas.

Consider just one organization that could channel feminist research into other arenas. The Leadership Conference on Civil and Human Rights (est. 1950) is a coalition of 200 labor unions, professional associations, law centers, church and philanthropic groups, and such feminist organizations as the National Organization for Women, National Women's Law Center, and National Women's Political Caucus. But women's studies organizations are conspicuously absent, thereby foregoing the opportunity to wed academic knowledge to the Conference's multi-issue coalition-building, advocacy, and activism. The separation of US women's studies from extra-academic arenas contrasts, as we will see, with the cross-sector reach of Indian women's studies.

16.1.3 Intellectualization

The intellectual core of any academic field consists of practitioners who investigate objects, deploy methods, form concepts, and produce knowledge. But they are not free agents: Rather, their intellectualization proceeds according to an underlying discursive order, in turn shaped by the institutional locus and reproduced by practitioner socialization.

Trained in mainstream disciplines that occluded knowledge of women, the 1970s feminists conducted research to fill the void. They unearthed women's lives, documented their contributions, and compiled data on such issues as sexual violence, reproductive care, educational inequalities, and employment discrimination. In turn, this work grounded critical analysis of societal and disciplinary sexism, which was undergirded by the assumption that male and female were different species, complementary and unequal. Biology cast sex differences as genetically determined and socially determining; history credited men with great deeds in the public sphere and consigned women to the private sphere; and literary studies attributed men's work to genius and women's work to fancy. Using transdisciplinary methods borrowed from the Second Wave, Marxism, and social constructivism, academic feminists developed gender analytics to show how material, social, and symbolic phenomena, including biology's "sex," were aspects of the sex-gender system.

During this phase, feminists of color, along with scholars in African American, Chicano/a, and LGBT studies, argued that the category "women" and gender analytics presumed a white, middle-class, heterosexual, Western identity and marginalized other identities. To be fair, some white feminists were (albeit simplistically) analogizing the oppressions of women and blacks, but others were pressing for nuanced analysis. In separate 1969 articles, historian Gerda Lerner warned that "women" obscured diversities of race, class, nationality, and other factors; and anthropologist Gayle Rubin noted that poor black women, situated at the conjuncture of classism, racism, and sexism, experienced triple oppressions. Criticizing dual-systems (racism + sexism) and triple-systems (racism + sexism + classism) theory, sociologist Deborah K. King argued that multiple oppressions had multiplicative, not additive, effects (1988, pp. 46–47).

In 1991, law scholar Kimberle Crenshaw introduced the phrase "intersectional analysis" to denote multifactor analysis and then demonstrated that women of color who experienced rape or battering were subjected to multiplicative effects. Her examples included shelters that rejected immigrant women for lacking fluency in English, advocacy of the 1991 Violence against Women Act, which foregrounded the plight of white middle- and upper-class women, stereotypes that resulted in treating black victims as less credible than white ones, and antiracist and antisexist movements that pressured women of color to choose one identity over others (pp. 1265–1282). Since then, intersectional analysis has spread to diverse fields from anthropology to advertising, education to economics, and itself has become a field of study (Cho et al. 2013).

Standpoint theory, chiefly developed by political scientist Nancy Hartsock, philosopher of science Sandra Harding, and sociologists Dorothy Smith and Patricia Hill Collins, shifted the discourse to the meta-level of epistemology. Rejecting the positivist-empiricist claim that disinterested researchers use rigorous value-neutral methods to produce peer-tested truths, the theorists also tackled other assumptions such as the subject/object binary and the capacity of language to transparently re-present reality. Drawing on materialist analysis, black feminist studies, and sociology of science, they argued that knowers' perspectives and practices were constituted by their socialization into gendered, raced, and classed disciplines and societies. Criticizing both white men and white feminists for blindness to their epistemic privilege, standpoint theorists advocated for incorporating the persons, perspectives, and knowledges of marginalized peoples (Hekman 1997).

In the 1980s and 1990s, waves of theory—feminist, materialist, and poststructuralist—engulfed academe, roiling classrooms and publications. Materialists clashed with poststructuralists for proclaiming the instability of language, dismantling categories, decentering the humanist subject, and celebrating the endless play of interpretation. Contradictions surfaced in feminism—calls to recognize marginalized groups of women yet deconstruct the category "women," to empower individual women yet renounce the humanist subject, and to oppose structural oppression yet recognize performative identity. Strung out between modern and postmodern epistemologies, realist and nominalist assumptions, constructivist and deconstructionist methods, the knower's self-reflexivity and discourse's self-referentiality, feminists balkanized into intellectual camps. Today feminist scholars can choose any approach to any topic; in fact, they *must* choose because no one can master the field's vast empirical, theoretical, and epistemological territory.

16.1.4 Circulation

In the 1970s media corporations began acquiring publishers, newspapers, magazines, radio stations, television networks, film studios, music labels, talent agencies, and distributers. By the 1990s, a few global conglomerates dominated publishing—Bertelsmann, Disney, Newscorp, Sony, Time Warner, and Viacom. Bertelsmann, for example, owned Random House, a holding company for 40 presses and imprints; and Newscorp owned HarperCollins, with 30 presses and imprints. Whereas once the profits from best-sellers had subsidized titles with low print runs, now conglomerates required each one to reap a profit (Croteau et al. 2012, pp. 32–42, 59–70).

Second Wave feminism arrived during the early years of conglomeration. Publishers fed the growing feminist market with Kate Millet's *Sexual Politics* (Doubleday 1970), Robin Morgan's *Sisterhood Is Powerful* (Random House, 1970), Germaine Greer's *The Female Eunuch* (McGraw-Hill, 1971), and Vivian Gornick and Barbara K. Moran's *Woman in a Sexist Society* (Basic Books, 1971). But these profitable best-sellers did not persuade scholarly presses and journals to publish feminist scholarship; between the mid-1960s and mid-1970s, university presses issued little more than a half-dozen feminist books, and mainstream journals published about that many feminist articles. Needing material for research and teaching, feminists founded *Women's Studies* (1972), *Feminist Studies* (1972), *Signs* (1975), and other journals. Initially the first two published both academic and activist work, but *Signs*, sponsored by the high-status University of Chicago Press, profiled itself as a rigorous interdisciplinary journal that held articles to high scholarly standards. Other journals eventually followed suit and, together with mainstream venues, academized feminist knowledge (Messer-Davidow 2002)

In the United States, feminist studies achieved exponential growth because it had more resources than other new critical studies: It had thousands of practitioners and an apparatus consisting of both feminist and disciplinary programs, associations, and publications. Growth, however, had paradoxical effects. With increased output, feminists won places on editorial boards, grant panels, and promotions committees. But the increasingly esoteric knowledge they produced distanced them from nonacademic communities while entangling them in retheorizations of the already said.

16.2 India

In this section, I argue that Indian women, traditionally excluded from or marginalized in Indian higher education, which continued to bear the imprint of British imperialism, institutionalized a social-change oriented feminist studies in multiple sectors.

16.2.1 Emergence

Indian women participated in three waves of struggle, the first challenging British imperialism. In the nineteenth century, Britain expanded the agricultural and industrial sectors, set up an English-style education system, and grew the middle classes. But it also imposed forms of domination that provoked unrest, particularly intense in Bengal with its capital city of Calcutta (Kolkata) and Maharashtra with its capital city of Bombay (Mumbai). Women demonstrated to improve female education, pass protective labor laws, abolish child marriage and sati (widow immolation), and ease fundamentalist Hindu and Muslim restrictions (Kumar 1993, pp. 7–31). Later they protested British soldiers' rapes of Indian women and promulgated a discourse celebrating women novelists and mother-goddesses.

During the second wave—agitation for independence finally won in 1947—women campaigned for Home Rule and founded local protest organizations that, however, were suppressed under the 1919 Seditious Meetings Act. Although joining Gandhi's All India Congress and participating in massive protests against the British salt monopoly, foreign liquor, and imported cloth, many women had reservations about his ideology of sexual differences and complementary social roles. Feminist nationalists circulated an equality discourse that radicalized traditional women's groups, but at a cost. For instance, the All India Women's Conference (AIWC), founded in 1926 to advocate for female education, rallied thousands of women to press for suffrage, land and inheritance rights, better labor conditions, child welfare, and representation in government, but this broader agenda alienated its Muslim members (Chaudhuri 2004).

Contradictions precipitated the third wave of struggle. After independence, the optimism aroused by the constitutional affirmation of women's equality and reform of laws on marriage, adoption, and inheritance was blunted by the realities. In 1971 the government established a Committee on the Status of Women in India (CSWI) whose members—educators, social workers, policy makers, and other professionals—were tasked with evaluating women's progress. The findings, published in *Towards Equality* (1974), sent shock waves through the public. With the exception of education for middle-class women, "the condition of the vast majority of women had been deteriorating since the 1950s" (John 2008, p. 3): Females suffered high mortality rates, many forms of violence, widespread poverty and illiteracy, and low participation in governance (Velayudhan 1985; Mazumdar 2008).

Awakening locally, poor women who worked in petty trades, street vending, and agriculture in the state of Gujarat formed the Self-Employed Women's Association (SEWA) in 1972. After overcoming official resistance, they registered SEWA as a trade union but soon expanded its portfolio to research, literacy and skills training, banking, and technology distribution such as vents for home cooking (Datta 2003). At the other end of the class spectrum, female members of the Progressive Democratic Student Organization at Osmania University in Hyderabad realized that the gender ideology infusing this organization curbed their academic ambitions. After reading work by Simone de Beauvoir, Betty Friedan, and Shulamith Firestone, they organized a convention that attracted hundreds of women and founded the socialist-feminist Progressive Organization of Women (POW) in 1974. This organization established branches at other colleges and organized dozens of protests, but its activism was quashed during the 1975–1977 state of emergency (Lalita 2008).

The women's nongovernmental organizations (NGOs) that proliferated in the early 1970s spread feminism to low-income, low-caste, and rural women and achieved "a significant shift in the analysis and understanding of women's issues." They enlarged the movement's agenda "beyond the traditional concerns with legislation, education and social welfare to a wide range of issues, such as access to land and natural resources, environmental degradation, media, reproductive health and population, gender violence . . . communal and caste conflicts, and representation of women" in local councils (Patel 1998, pp. 156–157). By fusing research and education projects to their activism, the NGOs provided a model for Indian women's studies.

16.2.2 Institutionalization

After *Towards Equality* was released in 1974, women at SNDT University in Mumbai established the Research Centre for Women's Studies (RCWS). Although further institutionalization stalled when Indira Gandhi, India's first woman prime minister, declared a state of emergency from 1975 to 1977, some groundwork was laid. In 1975 Indian women attended the United Nations' International Women's Year conference, and in 1976 the Indian Council of Social Science Research (ICSSR) announced a program to develop social-science research on women. In 1981 the First National Conference on Women's Studies, cosponsored by the RCWS and NGOs, was held at SNDT Women's University; there several hundred academics, policy makers, and activists founded the Indian Association for Women's Studies (IAWS), which went on to organize 12 major conferences as well as smaller events that spread feminist ferment (Indian Association of Women's Studies, 1991, 2014).

In 1986 the University Grants Commission of India (UGC) invited proposals from universities wishing to establish women's studies centers; with this support, the centers grew from four that year to 66 in 2011 (John 2008, p. 13). Believing that the centers should address urgent societal problems rather than build curricular programs, academic researchers "actively initiated steps through NGOs and non-university-based research institutions to transform their findings into realistic social utilization" and disseminated results throughout the grassroots level (Kaushik 2014, p. 14). Today all centers orient their activities toward improving women's lives, most "sprinkle" teaching materials into disciplinary courses, some are expanding their course offerings, but very few offer degree programs.

Inventorying women's studies today is difficult because its institutional forms include not only the university centers but also research and education programs housed in academic associations, publishing houses, unions, NGOs, and government agencies. Thus compared to the US field, Indian women's studies has proportionally fewer academic units, but its institutional forms are far more integrated across sectors (a profile also occurring in some African and Asian countries that have fewer universities and less female access to them). Expansive though it is, Indian women's studies still struggles against the rigid traditionalism of universities, the widespread mores concerning women's place, and the resurgence of religious fundamentalism (Velayudhan & Hydari 1982; John 2008; Mitra et al. 2013; Kaushik 2014).

16.2.3 Intellectualization

After independence, Indian organizations that had united to oppose British rule balkanized. Members of the Communist Party of India (CPI), the dominant force in hotbed cities and states, not only broke from other groups but also splintered internally around gender and class issues. While most feminists agreed "that a materialist framework was necessary for the analysis of women's oppression," they vigorously debated whether any "commonality of women's experience . . . could cut across class, and to a lesser extent caste or community, boundaries" (Kumar 1993, p. 100). The debate between advocates of gender analysis and class analysis was resolved not by critique, as in the United States, but by empirical data revealing the divergent circumstances of Indian women by gender, age, class, caste, race, ethnicity, religion, and locale. Thus the development of intersectional analysis in India was an enormously complex undertaking.

That the methods of Indian women's studies differ from those in the United States is owing to epistemic assumptions and populational diversity. First, the Indian unit of analysis is the specific collective, not the Western abstract individual, because Indian researchers view individuals as inextricably embedded in family, community, and other networks. Second, since quantitative methods cannot accurately generalize from diverse populations to an all-India picture, researchers quantify only with respect to specific groups in specific locations, relying mainly on case studies and textured prose to capture the variegated socioeconomic and cultural experiences. The subject/object division characteristic of US research and enforced by Institutional Review Boards does not guide Indian scholars; instead they interleave the voices of other women with their own and indigenous thought with intersectional analysis.[1] These methods place the research close to the lived experience of Indian women and make it easy to disseminate in writing and speech (Purkayastha et al. 2003; Mitra et al. 2013; Kaushik 2014).

Let us consider accounts of an infamous sati incident in the Sikar district of Rajasthan. Sati ideology held that a widow voluntarily consents, dresses in her bridal clothing, enters a mystical state, lights the fire herself, and feels no pain as she burns into a purified state. Feminist accounts told a different story about the immolation of Roop Kanwar, an 18-year-old woman from an affluent Jaipur family. Married to the 22-year-old son of a schoolteacher in the village of Deorala and widowed eight months later, she was burned in 1987. As the sati was being planned, Kanwar fled but was caught and drugged, marched to the site by armed guards, and restrained on the pyre. Some 2,000 people gathered to witness the event, but her male relatives and the police were conveniently absent. Afterward, her father-in-law and other male villagers formed the Deorala Trust to accept donations and commodify the site as a place of pilgrimage with stalls for souvenirs and snacks.

Feminist accounts, circulated through protests and publications, analyzed cultural, political, and economic circumstances that enabled sati to occur despite long-standing attempts to outlaw it by the British and Indian governments. Historically, conservative Hindus had painted sati as a mystical female act that affirmed the masculinity of husbands, but in the 1980s they deployed it in wedge politics, pitting their ideology of Indian traditionalism and spirituality against feminism's alleged ideology of Westernization and secularization. Feminist accounts of Kanwar's immolation thus stressed the desire of Rajputs and Brahmins in Rajasthan to recover lost political power, reverse economic decline, restore ethnic group identity fractured by caste and class differences, and combat women's modernization (Vaid & Sangari 1991; Kumar 1993, pp. 173–181).

16.2.4 Circulation

Modern publishing in India began as a colonial project to acculturate Indians and create markets. In the late nineteenth and early twentieth centuries, British publishers imported school books for the new English education system and then opened offices in major cities; Macmillan, Longmans, and Oxford University Press quickly monopolized the English-language market. For most of the twentieth century, Indian publishers were hampered by foreign dominance, high paper costs, weak distribution networks, low income levels, high illiteracy rates, and India's multiple languages.[2] But propaganda and profit continued to

[1] Several of these features—rejection of self/other and subject/object binaries, inclusion of subaltern speech, and indigenous knowledge-building—typify postcolonial studies.

[2] The literacy rate of 18% in 1947 rose to 65% in recent years, but many Indians knew only their local language and perhaps Hindi, the official national language. The Indian Constitution recognizes 22 Indian languages, and today the industry publishes in all of them plus English and ancient Sanskrit.

lure foreign entities to India. The subsidized books distributed by the Indo-US Program and the US Information Service, along with the offerings of AOL Time Warner, Disney, and Newscorp, transmitted Western geopolitical and disciplinary biases. But by 2003, India had 16,000 foreign and indigenous publishers who issued 70,000 books annually, the country ranked third after the United States and the UK in English-language book publication and seventh or eighth for overall sector size (Malhotra 2006).

Feminist publications emerged during the period of nationalist struggle. Founded by British feminists in Madras and later edited by Indian women, *Stri Dharma* ("sphere of woman," 1918–1938) published—in English, Hindi, Tamil, and Telugu—articles on women's issues, Gandhi's speeches, and protest announcements. But the journal's advocacy of international sisterhood was undercut by the growing awareness of Indian women's diversity, and its theme of women's empowerment raised anxieties over expanded female roles (Tusan 2003). After independence, the prestigious *Economic & Political Weekly* (1949–) was founded to publish the work of "academics, researchers, policy makers, independent thinkers, members of non-governmental organizations and political activists" on a full range of issues ("About Us"); in 1985 it began devoting two issues per year to women's studies ("Review Issues").

The first feminist journal, *Manushi: A Journal about Women and Society* ("human being," 1978–), was sponsored by the Manushi Trust, which also provided legal aid and organized advocacy campaigns ("About Manushi"). The journal was conceived to bridge "the divide between research and activism." Read by "activists, scholars, academics, journalists, professionals, housewives, policy makers . . . and . . . concerned citizens," its articles have been translated into regional languages, reprinted in newspapers and magazines, and republished in book form ("Manushi").

The first feminist press, Kali for Women (a Hindu mother-goddess, 1984–), was started in a Delhi garage by two Indian women who had worked at Doubleday, Oxford, and Zed Books. Cofounder Ritu Menon felt that the vibrant women's movement, the new women's centers, the growing literacy rate, and the women's lists of Western publishers made an unabashedly feminist press feasible. Kali has two English-language imprints: Zubaan ("voice" or "language") issues academic classics, cutting-edge scholarship, creative writing, and children's books, while Women Unlimited publishes social sciences, creative writing, children's books, and activist materials. To compensate for India's weak infrastructure, Kali publishes and distributes with The Feminist Press, Zed, Verso, South End, Westview, Rowman & Littlefield, and university presses at Chicago, Michigan, Minnesota, Rutgers, and Wisconsin (Fraser 2007; Zubaan 2015; Women Unlimited 2015).

Stree ("woman," 1990–), the imprint of two presses, is staffed by seven people, yet its publications reach across languages and castes, Its Bengali list includes academic and literary titles targeted to 200 million Bengali speakers, and its Samya ("equality") list publishes books for and about Dalit women (the caste formerly called "untouchables"). The imprint faces challenges: "By remaining in a cottage-industry mould, in an environment that is beginning to be dominated by multinational corporations (MNCs), Stree could find it hard to survive." To gain stability, it copublishes and distributes with like-minded large and small presses (Sen & Bhowmik 2002, quotation 190).

In India, feminist publishers, centers, and NGOs all issue academic, activist, and popular materials, often in multiple languages. But the circulation of women's studies discourse still depends heavily on in-person modalities, such as conferences and protests, to reach illiterate women. With the exception of websites, US publishing does not span the sectors; rather, academic, commercial, professional, and advocacy publishers niche-market their materials to within-sector constituencies. That is one reason why US feminists and progressives need to collaborate on building cross-sector apparatuses.

16.3 Feminisms, Neoliberalisms, Globalisms

Since the mid-1980s, globalization has been a hot topic in international agencies, policy forums, and corporate circles; somewhat later public interest was aroused when families and communities began to experience the effects of economic and social restructuring. In academe, globalization is investigated in mainstream disciplines, interdisciplinary fields, and recently established global studies programs. One stream of critical literature emanated from postcolonial studies, which probed the historical and contemporary phases of economic, political, and cultural imperialism. These critics denounced the Enlightenment rationality and Eurocentrism of both disciplinary and imperialist regimes. Another stream of critical literature emanated from fields concerned with specific transnational systems, such international relations, public health, development programs, and communications.

In a 2002 literature review, Douglas Kellner described globalization as a complex formation in which transportation and communication technologies, mediating institutions, and transnational capital enable the "global flows of goods, information, ideologies, and people" (p. 290), restructuring virtually all intra- and international activities. Investigating it, however, many scholars still rely on familiar disciplinary methods and topics. For instance, studies of production are often disciplinarily divided into accounts of export-processing zones, financial data on multinational corporations, critiques of worker exploitation, and interpretations of working-class literature. As V. Spike Peterson observed, disciplines retain their grip, fragmenting our knowledge of "multidimensional phenomena [that] require cross-disciplinary orientations and a combination of empirical, historical, and interpretive insights" (2009, p. 31). Many scholars also fail to interrogate globalization's neoliberal form and its disparate impact by gender, race/ethnicity, class, and locale. For instance, although Gary Gareffi's 2008 article on transnational commodity networks provides an insightful picture of the apparel industry's global supply chains, segmented US consumer markets, and megacorporations like Walmart, it does not discuss neoliberalism and its disparate effects.

Both US and Indian feminist scholars use intersectional analysis to capture globalization's disparate effects, but they treat its neoliberal form differently. Whereas US scholars write critical histories of neoliberalism in the United States, UK, and elsewhere, Indian scholars foreground the relays between macrostructures and local conditions, a number of studies showing how India's economic reforms played out on the ground to the detriment of lower-class or -caste women and children. In a 2014 book of comparative case studies, Jana Everett and Sue Ellen M. Charlton acknowledge, "The United States is unique for its philosophical and cultural emphasis on individual agency" and its belief "that people can easily escape" structural constraints (p. 6).

Moreover, Indian feminists often link seemingly unrelated neoliberal phenomena, such as structural adjustment programs (SAPs) and Miss World pageants. As a condition of receiving SAP loans, provided by the World Bank and International Monetary Fund to alleviate economic crisis or advance development, a borrowing country must adopt such neoliberal measures as lowering wages, reducing taxes on high incomes and profits, deregulating businesses, eliminating price controls, trimming government programs, privatizing public services, devaluing currency, and increasing exports. Studies, many by Western scholars, show that in most cases SAPs, rather than improving the borrowing country's economy, have slowed industrial production, diminished agricultural output, stalled economic diversification, and increased poverty. But feminist work reveals that SAPs do not have gender-, class-, or locale-neutral effects: In India, as the government trimmed public schooling and hospitalization, women in high-income families simply paid for private services, but poor ones were forced to undertake this work themselves and, paradoxically, had less time for the paid work and subsistence agriculture that feed the family (Sadasivam, 1997).

In Rupal Oza's *The Making of Neoliberal India* (2006), the story also began with India's neoliberal economic reforms but turned to other effects—the growth of middle-class consumer culture as the media saturated the country with images of the "new Indian woman" who, through consumption, became stylish, sexually alluring, and professionally confident. Oza examined how consumer images infused the Miss World competition while simultaneously heightening anxieties about the diminution of male authority and national sovereignty. The two types of literature suggest that when India welcomed SAP loans and beauty pageants to obtain the promised economic and cultural capital, it also acquired neoliberalism's gendered, sexualized, and classed effects.

Indian research captures global dynamics in ways that US research does not (see Grewal 2005). The SAP studies show how neoliberal globalization oscillates between the productive and reproductive economies, while the Miss World studies show how it oscillates between the material and symbolic registers. Other research tracks its movement from macro- to microlevels, such as a study of government-sponsored NGOs that used empowerment discourse to plant neoliberalism in communities of poor and low-caste women. "Empowerment," Sharma remarks, "when examined through the lens of neoliberal governmentality, is a double-edged sword," promising self-determination but often creating state subjects (Sharma 2006, p. 82). Many US feminists have produced important analyses of inequalities in education, employment, income, healthcare, welfare reform, and immigration. But relatively few studies connect the dots back to neoliberal globalization, thus failing to recognize that the restructuring imposed wholesale on SAP countries in Asia and Africa is being imposed piecemeal here.

The differences noted in this chapter take us back to my contention that the form of feminist studies depends on location. The location of US feminist studies in the higher education system locked the field into the grip of the institutional-disciplinary order. Although feminist studies built a cross-hatched infrastructure consisting of its own and disciplinary apparatuses, it did not escape academe's regulatory pressures and its incentives to proliferate specialized research. By contrast, the multiple locations of Indian women's studies in academic centers, associations, unions, NGOs, government agencies, and grassroots women's communities gave it cross-sector reach, but did not free it from within-sector pressures. In both cases, institutional form interacted with intellectual orientation: US feminist studies became an academic enterprise for producing and circulating knowledges that met institutional-disciplinary standards, while while Indian women's studies became a project to channel hybridized academic and indigenous knowledges into social change.

Globalization may prove to be the ultimate vehicle for transcending both disciplinary and national boundaries. This compendious object calls for large-scale and small-scale collaborations increasingly facilitated by travel and technology. In the recent past, unprecedented crowds from many nations gathered at the UN World Conferences on Women in Mexico City 1975, Copenhagen 1980, Nairobi 1985, and Beijing 1995, where 47,000 individuals (almost all women) represented 180 countries and 200 NGOs.[3] These conferences fostered appreciation of within-country differences, awareness of between-country specificities, and plans to internationalize research and teaching.[4] Since then, sophisticated digital and social media make virtual interaction a reality that transcends geographic location. Going forward, feminist studies may well have new questions: Can we develop more complex types of intersectional analysis? Can we analyze neoliberalism's "glocal" (i.e., global-local) relays and uneven impacts? Can we mute the negative effects of globalization? It depends, I think, on whether we can develop transnational infrastructures to support the cross-sector production and circulation of knowledge for the public good.

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[3] *UN Women* reports that 17,000 participants attended the main conference and 30,000 attended the parallel NGO Forum held near Beijing (www.unwomen.or/how-we-work/intergovernmental-support/world-conferences-on-women). These numbers vary somewhat depending on the source reporting them.

[4] In the mid-1990s, the Ford Foundation funded 13 university projects to "internationalize the study of women throughout the United States"; among them, the University of Michigan launched an ambitious Global Feminisms Project that created a print and audiovisual archive of feminisms in China, India, Poland, and the United States. Meanwhile several journals published special issues on global feminisms including *Women's Studies Quarterly* (1998), *Women's Studies International Forum* (1999), and *Signs* (2001) (Stewart et al. 2011, p. 890). Between 2005 and 2010 *Signs* broadened its geographic scope: 52% of all articles published during these years were written by scholars from nations other than the United States, and 66% of the article content focused on geographic sites other than the United States (Hawkesworth 2011, p. 513).

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CHAPTER 17

HUMANE SMART CITIES

EDUARDO M. COSTA AND ÁLVARO D. OLIVEIRA

Today more than 50% of the world's population lives in urban areas. There is no sign of reversion of this trend; United Nations studies point to a staggering 66% figure by 2050 (United Nations 2007 and 2014). China alone will place 300 million people in cities within this time frame—the equivalent of one United States! The impact of this change on "livability" (the sum of the factors that add up to a community's quality of life) in the cities and the earth's resources will be dramatic.

Most cities face severe urban problems like traffic jams, pollution, and social exclusion. It is crucial that cities of the future do not develop according to the old paradigm of spatial segregation of daily functions. It is time to shift our attention to designing a better living experience in our cities: They should be flexible and respond to their citizens' wishes and needs. Technology will help. But let us place the right questions now—all related to who is really important: people, rather than cars or cameras or control centers.

European villages in medieval times tended to be small, circa 1-mile radius. Within this geographical area people lived, worked, played, and prayed. One of the practical limitations to growth was water: villages not close to rivers would usually have one clean-water well in the main square, making it difficult to carry water home in heavy buckets. Centuries later, Paris was redesigned by Baron Hausmann in 1860 as a collection of four boroughs of around 1 mile radius each. In each of these boroughs people could then (and still can now) live, work, and play. The main change was brought about by the arrival of the car in the twentieth century. Cities were segregated spatially into residential, commercial, and entertainment areas as people commuted between them in cars. The end result is what we see today: traffic jams, pollution, accidents, and urban distress.

A new concept and field of study has evolved to study this issue: the humane smart city. It consists of all the interdisciplinary subjects that must interact in order to make cities more sustainable. A great deal of attention has been devoted in recent years to the idea of smart cities. Suppliers of technology in particular have been eager to push the smart city concept. A smart city is in general associated with technology: sensors, cameras, fast Internet connections, and control centers. While useful, technology should not be the central focus. A humane smart city addresses first of all people and their needs. Then comes technology and only in direct connection with these needs. The point here is to raise the right questions. Rather than needing a solution to traffic jams, we need a solution to the mobility of the people who today are trapped in the chaotic jams. Answers to these different questions are very different indeed and may lead to significantly different solutions.

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Humane smart cities have been defined by the European Union around six fields of study: smart living, smart people, smart governance, smart mobility, smart environment, and smart economy (Giffinger et al. 2007). As the concept was transposed to emerging countries, a new field of study has been added to these six: smart social inclusion. It tackles poverty in cities and the problems associated with rapid growth and geographical expansion. In all of these seven fields there are good and bad examples to learn from, and cities are organizing themselves to exchange knowledge and share their experiences.

Solutions to cities' problems are inevitably interdisciplinary in nature. They involve the social sciences, with studies on people's behavior in communities (see the MyNeighbourhood project, discussed below), urban studies of spatial distribution of people and functions, and studies of social networks and their use in the context of cities (see the Periphèria project. discussed below). These solutions also involve studies of computer technology of sensors and high-speed connections, electronic and participatory government, and big data and business intelligence.

This chapter describes these aspects of humane smart cities and proposes pathways to those who are interested in getting involved in the subject. Cities can be great places to live, where one can find more opportunities for work and personal development. But problems are mounting as we insist on the current models of transport by private car and spatial distribution of the functions of live, work, and play. This chapter examines how we keep the good things we like in the city and avoid the bad ones that were brought about by poor planning and wrong models of urban development.

17.1 Introduction

Cities face challenges every day to create prosperity and ensure good quality of life. As the world increasingly adopts advanced communication infrastructures and other information and communication technologies (ICTs), social cohesiveness in the city environment appears to have been progressively lost (Fry 2011, p. 25). The uncertainty about what social models result from the digitalization of society calls for decisive participatory actions from public and civil authorities in cities.

Due to the steady urbanization of our societies, it is becoming increasingly difficult for city authorities to provide suitable services to address citizens' needs. Issues such as demographic shifts, health, security, sustainable housing, transportation, energy, and environment primarily affect cities and are perceived by citizens as key factors for their quality of life. City administration has to play a strategic role in the conceptualization, development, and implementation of adequate responses to local or global societal challenges they face today. This is particularly challenging in a context of crisis and mistrust between citizens and public administrations. Information and communication technologies ensure that critical infrastructures and utilities are managed more efficiently. But this is clearly not enough.

In the context of urban innovation, it is of paramount importance to place citizens at the core of strategic thinking. Cities are smart when they take full advantage of the human capital of its citizens, create innovation ecosystems where new dynamics of wealth and job creation take place, and promote new forms of participatory governance. In short, when they become humane smart cities.

Humane smart cities use technology as an enabler to connect and engage government and citizens, aiming to rebuild, recreate, and motivate urban communities, stimulating and supporting their collaboration activities. This leads to a joint increase of social well-being. In a humane smart city, people rather than technology are the true actors of the urban "smartness."

17.2 A Brief History

In the typical medieval village all the work, living space, and entertainment were local. Villagers did not travel very often and certainly not for daily work. This arrangement lasted until the overall development of merchant trade and large cities evolved all over Europe and other regions in the East.

In mid-nineteenth century, the French emperor Napoleon III hired the then-mayor of Bordeaux, Georges-Eugène Haussmann, to redevelop Paris as a symbol of his empire. Haussmann planned Paris with four arrondissements (later 20, as today) and pulled down old buildings and dwellings to open large avenues, parks, and also to promote sanitation for the town. Although the urban concept was significantly different from medieval villages, Haussmann kept the arrondissements small (typically 1 mile square each). The large avenues we admire today, like the Champs-Élysées, were not built for cars but for the passage (and glory) of Napoleon's troops.

Beginning in the late 1800s, and increasingly after the early 1900s with the arrival of the car in Europe and in the United State, urban development adopted the idea of segregating the main functions of working, living, and playing in different sections of most towns. City sprawl ensued. Cars became the preferred (and desired) means of transport mainly between residence and work. This worked well for parts of the population while the number of cars was small. Eventually it led to traffic jams, pollution, and accidents.

Even given its many problems, the car is accorded such reverence today that most people do not even question its cost, neither the public cost nor the private one. Local governments usually face no difficulty in approving a road enlargement, for instance. It is as if anything to improve the situation of the car were positive. Think of the cost of the car to our society in terms of health issues, accidents, pollution, urban land space, viaducts, roads, and so forth. In spite of that, in order to give incentives to local industries, governments tend to tax the car industry at a minimum. In Brazil, the overall tax on the supply chain of a car is 37%. In the supply chain of a bicycle, it is 43% (O Globo 2014). The private cost of the car is also overlooked. In emerging countries, the cost of owning and maintaining a car tends to be the costliest item in a family's budget.

The humane smart city changes the focus from the car to the people and from segregation of the functions of live, work, and play into its full integration in every borough of the city.

17.3 From Smart City to Humane Smart City

The rapid urbanization of societies raised a completely new set of challenges related to efficient mobility and parking, sustainable environment, quality delivery of water, assurance of low levels of pollution, reduction of energy consumption, adequate lighting, and proper treatment of waste. The concept of the smart city emerged to ensure that the various urban production factors, including investments in traditional and dematerialized modern infrastructures, could be addressed through a common perspective and framework, making cities more effective and "intelligent" in addressing such challenges. Encouraged by a vision of the hyperconnected society, city authorities started exploring ICTs to increase their ability to observe, monitor, learn, digest, decide, and act on the various relevant factors that may make a city more effective.

Using the Internet of Things (IoT) all relevant data could be collected providing an integrated overview of all city processes. The intensive use of models and data analytics, processed most likely in computing clouds, would complete the understanding of the city as a machine, and allow for acting in the real world in order to adapt to new circumstances (see the concept in Fry 2011, p. 16). Cars can be directed to the available parking places; ambulances can be rerouted, avoiding congested zones; unnecessary consumption of energy can be rationalized; citizens can be warned in advance regarding environmental conditions, and so forth.

But the challenges are bigger and call for a more radical social transformation, affecting the way we all work, live, play, and build our future. This change in turn places a special burden on those holding the responsibility to govern such processes with an optimum usage of the public resources available. An expert analysis of a large number of smart cities implementations has led us to conclude that a mere technology-driven implementation of the smart city concept, although being an important step in the right direction, falls short in exploring the most important dimension of cities—their human and social capital (Woolcock & Narayan 2000) available in every citizen and collectively in the society (Oliveira & Campolargo 2015). In other words, it is important to return to the initial steps of the urban innovation process to reposition citizens at the core of the strategic thinking and planning of the modern city.

The creation of a participatory innovation ecosystem is the driving force for the establishment of an environment in which citizens and communities interact with public authorities and knowledge developers, in a collaborative mode, exploring the power of codesigned user-centered innovation services. This also calls for new governance models that lead to the urban transformation where citizens are the main drivers of change. Through their empowerment and motivation, major city challenges can be addressed. The great challenge is therefore not to install the infrastructure or adopt new technologies but to involve the public sphere in the civic life.

The humane smart city concept is built on emergent, sustainable models for urban living, working, and governance enabled by future Internet infrastructures and services. This perspective balances the technical "smartness" of sensors, meters, and infrastructures with softer features such as clarity of vision, citizen empowerment, social interaction in physical urban settings, and public sector–citizen partnership. The approach must be interdisciplinary, with emphasis on composite knowledge. Thus we can label the study of the humane smart city in the *composite interdisciplinarity* field (Klein 2010, p. 18).

The humane smart city approach is gaining increasing support from city governments across Europe as well as from the research community (Marsh & Oliveira 2013). It more effectively addresses key challenges such as low-carbon strategies, the urban environment, sustainable mobility, and social inclusion (Murray et al. 2010) through a more balanced, holistic approach to technology. In this approach the government agrees to be engaged and involved in citizens' initiatives on the basis of an open, transparent, and reliable relationship.

Information technologies are used where appropriate to solve social problems and address economic and environmental issues, focusing on the well-being and happiness of the citizens.

17.4 The Seven Characteristics of Humane Smart Cities

The European Union, through one of its case studies (Giffinger et allii 2007) defined six characteristics of smart cities: smart economy, smart people, smart mobility, smart living, smart environment and smart governance. In order to cater for the special conditions in the emerging countries, we added a seventh characteristic: Smart Social Inclusion.

17.4.1 Smart Economy

The smart economy moves away from traditional industry and is concentrated in services, particularly those related to the "creative industries." There are several definitions for the term "creative industry." For the purpose of this chapter we define it broadly as the economic activity involving human work that is not repetitive. It is curious to realize that even the word "industry" is peculiar in this context, since it involves mainly "services" not "industries." This reflects the fact that we still think of the private sector as "industry" although it is mainly involved with "services" today in most countries. Even the software sector, the paramount example of creative industry, likes to call itself the software "industry." Perhaps this is a way to make it look more important, as if industry were the only sector that really mattered.

The smart economy is diversified and involves all sectors of the creativity industry—software, medical services, entertainment, the arts, consultancies, artisans, gastronomy, financial services, and so forth. And how is it "smart?" These sectors involve human work and activities that are nonpolluting and well-paid jobs. They also generate most new jobs today, since the repetitive work that used to be done at factories is being progressively replaced by machines (Costa 2000). These sectors are so important for economic development today that many governments on different levels are providing them with incentives in the form of tax breaks, subsidized loans, and direct investment in order to attract smart people to their jurisdiction. There is a competition for bright talent now between towns in the same country and even between countries, all trying to attract creative industries to their shores.

17.4.2 Smart People

Smart people are associated with education—they have more years of study than the average—but that is not the only characteristic that is needed in the smart economy. There are artists, performers, artisans, painters, dancers, and other types of creative people. The two groups mingle very well in some cities. Through their interaction, they produce new goods and services that are characteristic of the new economy. The smart economy attracts smart and creative people to work in its geography through all sorts of incentives (Marques et al. 2015a, 2015b). And the reverse is also true: Places where the creative class (Kanter 1997) and the people exist in abundance are much more likely to develop a smart economy.

Smart people are eager participate throughout their adult life in many forms of knowledge-sharing courses and events. And they praise diversity: Richard Florida (2005) even states that smart people live in cities where heavy metal bands are numerous. Flexibility to adopt new ideas and concepts is also a common factor. Creative people move constantly, and it is a city's constant goal to keep them happy with all kinds of innovative services available so that they do not move elsewhere.

Smart people participate in their city's public affairs. They want to make sure that they are heard. A popular voice among smart people are the "greens," those who are particularly concerned with conservation of the environment. If someone in town is trying to cut down a tree, they appear in hordes to protest. The use of social media is strong among them, and they can mobilize a crowd in support of their arguments on their specific networks in a very short time.

A symbol of the decline in importance of traditional industry is the three-dimensional (3D) printer. As the technology evolves, 3D printers are capable of producing "industrial goods" that can be customized to the level of one per user, impacting every aspect of traditional industry. 3D printers are even capable of producing new 3D printers.

A change in behavior comes as a warning to large companies and city planners: Young and talented graduates tend to choose the city where they want to live *before* the company they want to work for.

17.4.3 Smart Mobility

A humane smart city is concerned with the mobility of its citizens to and from work, to and from universities, to and from amusement places. Henrique Peñalosa, the former mayor of Bogotá, coined a phrase that became popular: "A town has smart mobility not when the poor go to work by private car but when the rich go to work by public transport." The answer to the problem of traffic jams we face today is public transport. This change in perspective is not easy. Citizens are used to the idea that they have a right to drive their cars anywhere. And public parking (sometimes free) is in constant demand. In Angra dos Reis, one of the most beautiful locations in Brazil on the southeast coast, the town is separated from the sea by a huge free public parking lot that hides the scenery from its inhabitants. When they have the courage to get rid of this, people will look back and think, "Why didn't we do this before?"

Bike lanes have been built in many towns, but they should be segregated from car lanes. Where they are separated only by a painted lane, car drivers tend to behave badly: It is as if that precious real state was robbed from them. In addition to bikes and public transport, cities should pay attention to sidewalks, which should be the preferred mobility path. In many towns they are too narrow (cut short in order to make way for the cars), badly paved, and with many obstacles on the way, making the ride of a wheelchair, for instance, almost impossible. Urban planners should consider the public real estate as a most valuable commodity, to be used sparingly and in favor of those who use it most. Janete Khan, secretary of transport for mayor Michael Bloomberg of New York in the 2000s, measured how many people passed through Broadway throughout the day by different modes of transport. And found out that four times as many people walked on Broadway in relation to those that used cars. So she decided to prioritize and allocate space to pedestrians and bike lanes, and the new Broadway is there today to everyone's pleasure and admiration.

Such changes will take time. But they have to be enforced with positive and negative incentives. On the one hand we can offer better public transport, segregated bike lanes, and good quality sidewalks. On the other hand toll fees for cars downtown, expensive parking, and annual taxes on cars are some of the new rules that should be established. The true cost of the car to society is huge and has to be taken into account: not only air pollution and used tire disposal but also, most importantly, loss of lives, public health, cost of car accidents, and so forth.

17.4.4 Smart Living

As shown in the preceding items, the seven characteristics of a humane smart city interact with and contribute to each other. A smart place attracts smart people who construct a smart economy, and so on.

A place is considered smart when people see it as a good place to live in. It is diverse, in the sense that it caters for different people's wishes and needs. It also has interesting tourist attractions that contribute to the sharing of experiences and knowledge between the locals and outsiders. It offers good-quality services in terms of schools, hospitals, clinics and public safety. And it demonstrates social cohesion: Different income levels of society mingle in a smart place with little signs of class tensions or racial hatred.

Some places have built their "smartness" around a symbol, a monument or an urban redevelopment project. The Guggenheim Museum in Bilbao, for instance, changed the local feeling and the international perspective of the town from a conflict zone torn by civil war to one of the most visited and interesting places in Spain and Europe. The redevelopment of the old industrial district of Poblenou in Barcelona into the @22 initiative projected the town as an international model of "smartness" that is being copied everywhere. Rio de Janeiro has also developed its old harbor into a new area (the "Porto Maravilha"—"Marvelous Port"), a movement that occurred in many cities, on a massive scale. The old medieval village principle of live, work, and play locally is a common feature across all these examples.

17.4.5 Smart Environment

A place that intends to become smarter takes care of its environment. Some of this is a given: natural resources such as rivers and greenery. But the major part is a matter of control and active intervention. For instance, pollution caused by CO_2 emissions is a definitive measure and should be followed closely. Electric transport vehicles help; so do the implementation of penalties or tolls on the use of private cars. But there are also softer measures that can make a significant contribution. For instance, why do most cities stick to the rigid 9-to-5 work hours in every sector? This is a heritage from the industrial era, when all the workers on a production line had to be there at the same time. Today a flexible work time (anchored by flexible labor laws) could do wonders to avoid massive traffic jams at peak time—and also to reduce all the pollution that comes with it.

The green movement, even allowing for its excesses, made a major contribution to our awareness of the finite nature of natural resources. A smart environment place is noteworthy in the way it uses and conserves its natural resources (see the Save Energy project, below). Reuse of water, collection of rain water, smart buildings that consume less energy, LED lamps for public lighting, smart garbage collection, and recycling and disposal are all well-established technologies that can be used by many towns. And strikingly, they may cost less in the long run than the existing methods. But why are they not adopted by all? Inertia offers a partial explanation. The fact is that governments tend to spend money on projects that are obviously visible and thus may lead to votes. For instance, a new LED-driven public lighting system does not register on public consciousness and does not add to the mayor's popularity.

The trend of city sprawl should be avoided. It is very expensive to provide public services over a long distance. And since most distant boroughs use downtown extensively, transport (mostly by private cars) adds to all the already existing problems in the town. In the words of Washington Fajardo, a city official in Rio de Janeiro: "the best city that exists is the city that exists already." Let us use the town that exists in a broad and interdisciplinary sense (Fry 2011, p. 26) to its full potential before moving to the outskirts.

17.4.6 Smart Governance

Considering the poor reputation of different levels of government (local, provincial and central or federal government) in many countries, citizens tend to gather this characteristic as the most difficult to develop. This should be no excuse for inaction though. With the advent of new IT tools and systems, it is increasingly easier to provide better services to society and many governments are pursuing that path. But the main change that is necessary in government is in the mindset of officials: from gate keeper to service provider; from authoritarian government to participatory government; from secret data to organization and full availability of data to citizens and companies; in a nutshell, from talking to listening.

17.4.7 Smart Social Inclusion

This characteristic is not part of the original six categories proposed by the European Union. But as the concept of humane smart cities has moved into less developed countries it becomes crucial. In the process of growing, sometimes at a very fast pace, cities in emerging but also in developed countries attract people from the hinterland and from abroad in search of better work opportunities. They cannot afford prices in town so they live in the outskirts, sometimes in dire conditions in slums. These communities need to be integrated into the local fabric of society as the city becomes smarter.

Priority number one (maybe two and three, as well) is the education of the young. But there are a variety of other initiatives worth pursuing. Job opportunities for the poor do not have to be necessarily related to manual labor. It might be better to consider arts and crafts that in the creative world can find a distinctive niche. Ethnic diversity may lead to opportunities in gastronomy, music, arts and crafts, and many other cultural manifestations.

Housing is a major problem for social inclusion, and some towns faced the problem with the provision of low-income subsidized rents. In this way poor workers do not have to travel many hours a day to get to work. Planning from City Hall is essential: The principle of live, work, and play in the same area should be open to all.

17.5 Examples of Interdisciplinary Projects

The National Academy of Sciences (2004) identifies in *Facilitating Interdisciplinary Research* four drivers of interdisciplinarity, as cited in (Klein 2010):

1. the inherent complexity of nature and society,
2. the desire to explore problems and questions that are not confined to a single discipline,
3. the need to solve societal problems,
4. the power of new technologies.

All these drivers are present in the study of human smart cities. The second driver may be stressed further and described not as the "desire" but the "urgent necessity" to explore problems that are not confined to a single discipline. Architecture and urban planning are being questioned as to their role in our changing societies and cities (Fry 2011, p. 16). The urge for new interdisciplinary—or more accurately described, transdisciplinary—projects in our universities is overwhelming, and human smart city projects constitute one prominent example. Yet, with few exceptions, universities tend to focus on subjects that are comfortably confined in their respective departmental silos. When the United States and some allies started the obviously interdisciplinary Manhattan Project in 1942, they went after the best knowledge that existed. And that was found at the independent Institute of Advanced Studies in Princeton, neither at the neighboring university nor at any other university for that matter. The situation has not changed much since.

The humane smart city concept aims at developing a citizen-driven, smart, all-inclusive and sustainable environment, with a new governance framework in which citizens and government engage in listening and talking to each other. And it is important to point out that the implementation of the humane smart city can be made through the use of frugal technology and does not always require sophisticated and complex infrastructures. This fact is relevant especially in what concerns the scalability of the solution. Simple and creative solutions can emerge from the local communities, which allow, for example, big cities to extend their strategies and include broad metropolitan areas, or small cities to integrate new strategies. This is an important advantage for city administrations, which enables the creation of humanly smart services without having to make significant investments.

17.5.1 Periphèria Project

The European Union's Periphèria project aims to deploy convergent future Internet (FI) platforms and innovative services for the promotion of sustainable lifestyles and work styles in and across emergent networks of smart peripheral cities in Europe. The project states that through the convergence of the sociotechnical elements that make up the new FI paradigms it is possible to reach more ambitious targets for economic, social, environmental, and cultural sustainability.

Central to this project is the concept of community interaction of people-in-places as the driving force of FI convergence (Weissbourd & Bodini 2009). Periphèria situates this interaction in six arenas—archetypical urban settings with well-defined social features and technological requirements—which become the "Living Lab" (Oliveira & Campolargo 2015) environments where codesign and integration of public services unfold. To each arena, an identified city partner is associated: Smart Neighbourhood, where media-based social interaction occurs (Malmö, SE); Smart Street, where new mobility behaviors develop (Bremen, DE); Smart Square, where participatory civic decisions are taken (Athens, GR); Smart Museum and Park, where natural and cultural heritage feed civic well-being (Genoa, IT); Smart City Hall, where mobile e-government services are delivered (Palmela, PT); and Smart Campus, a new arena formed by the Milan Polytechnic (project partner responsible for the arena modeling activity) as an extension of their original role in the project.

17.5.2 MyNeighbourhood Project

The MyNeighbourhood project is part of the European Commission ICT program in the field of smart cities. It aims at recreating and strengthening the social ties and interactions within the neighborhood. Paradoxically, the same ICT trends that have helped—in conjunction with other urban trends—to erode our connection to urban neighbourhoods and communities also have the potential to help reinvigorate them. A neighborhood, in most urban traditions, is an area shaped or determined by a social group that is created through bottom-up local processes (Meroni 2007). In the MyNeighbourhood project the aim is to promote qualitative and innovative solutions as well as the identification of a set of opportunities that will not only influence the neighborhood but the surrounding ecosystem of the city.

The MyNeighbourhood solution integrates new technologies and methodologies, such as social gaming principles (gamification), with the Living Lab methodologies to help create and strengthen existing ties and resolve communal issues in the real life of the neighborhood. The solution is rooted in an open MyNeighbourhood Platform that combines the data and functionality of existing "City Transformation Apps" with new tools that connect people locally, both on and offline. It uses gamification techniques to encourage people to get involved with their own neighborhoods and engage their family and friends to do the same.

Through this platform the city government can better implement measures such as participatory budget (citizens help decide what to do in the following year), citizen data mapping (to produce new services, even by the private sector), well-being services, participatory decision taking, and complaints management. These methodologies can bring huge social progress to the city, which aims, in the end, to promote democracy, listening and talking to the citizens.

17.5.3 Save Energy Project

According to the International Energy Associations World Energy Outlook 2008, 67% of global energy is used in urban areas, and cities are responsible for 76% of energy-related CO_2

emissions. The Save Energy project has developed evidence from its five pilot studies in public buildings in cities around Europe that substantial energy efficiency savings (in some cases over 20%) can best be achieved through engineering solutions in combination with changes in user behavior. The Save Energy project focuses on ICT provision that enables such user-behavior-changing solutions required to be most effective. The return on investment of these solutions ranges from 6 months to 4 years.

The Save Energy Green Paper (available at http://goo.gl/xtQckR) presents policy options to be implemented within the European Union and also internationally, in order to help cities implement this strategic role in public buildings. The main focus of the policy options is to assist in changing behavior through the range of tools and implementation process defined by the project.

17.5.4 Smart Campus Project

The Smart Campus approach builds on and improves the methodology used in the Save Energy project, which involved a centralized platform for metering energy consumption and providing real-time information to the users. Previously this communication was one-way only, that is, from the building to the users. Smart Campus also makes use of real-time information on energy consumption, but users have the possibility of actively interacting with the building energy management system that controls heating ventilation and air conditioning, lighting, and other equipment. The Smart Campus approach is thus based on interactive intelligent energy management systems with which the users can negotiate and define the building's environmental impact conditions. The results indicate that consistent savings derive from user behavior transformation.

Users are involved in the codesign of the energy-saving pilots in their campus (see, for instance, Helsinki Metropolia—University of Applied Sciences). The pilots themselves act as decision guidance tools, as they make it possible to show, compare, and increase the awareness, knowledge, and skills on energy efficiency. Decision guidance is also exercised by the "eco-motivators"—skilled people that integrate each user group associated to each pilot. The eco-motivators use information on the Smart Campus Portal to advise, discuss, train, and motivate all the user groups. The Smart Campus project disseminates and uses questionnaires, leaflets, project information, presentations, social media, posters, competitions, energy-saving tests, workshops, and exhibitions to enact decision guidance toward users involved in the different pilots.

17.6 Conclusion

The humane smart cities concept proposes the use of technologies as an enabler to connect and engage government and citizens, aiming to rebuild, recreate, and motivate urban communities, stimulating and supporting their collaboration activities, leading to a general increase of social well-being.

Humane smart cities call for new governance models in which public authorities listen to and speak with citizens. Policies and supporting services make the city government more transparent, participatory, and efficient and a mirror of the citizens' will. Humane smart cities empower citizens to codesign and cocreate solutions for their wishes, interests, and needs, recreating a new sense of belonging and identity, leading to a better and happier society.

The practical projects described in this chapter are based on the premise that citizens and neighborhoods represent a heretofore untapped, yet powerful, catalyst for humane smart city change. They aim to transform the city governance by engaging citizens in an open, transparent and trusted dialogue, enhancing and easing the interaction with the city administration. This makes it easier for citizens and businesses to transmit priorities and needs to city administration, reduces the need for time consuming face-to-face interactions with city administration, and removes the burden of bureaucratic processes by facilitating greater neighbor-to-neighbor exchanges.

The power of the humane smart cities concept and its proven impact on society calls for a strategic mechanism to be created or reinforced to celebrate achievements, share best practices, provide role models, and network like-minded city administrations engaged in the promotion of humane smart cities. Networks of cities will evolve and should be welcomed by us all.

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CHAPTER 18

INTERDISCIPLINARITY IN ETHICS

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Ethics is inherently interdisciplinary, yet not always pursued as such. This chapter is a selective, historicophilosophical effort to call attention to some aspects of interdisciplinarity in ethics in an increasingly global context.

18.1 Whose Ethics? Which Interdisciplinarity?

Ethics is constituted by critical reflection on human conduct, in order both to increase knowledge about and to improve socially or personally acceptable behavior. Because it involves critical reflection, ethics is not the same as morality. All human beings are influenced by morals, but not everyone reflects critically on the social guidelines for behavior. So in the first instance, those who practice ethics to any significant degree are the few in any society.

Within any society critical reflection on human conduct can be undertaken from different perspectives. In a second instance, then, the few who do ethics can bring with them different class, religious, professional, gender, or other perspectives—perspectives that will also require critical examination. Furthermore, third, different societies and cultures manifest even more substantially diverse worldviews. In an increasingly globalized world, interdisciplinarity in ethics must begin to accommodate such globalization, a movement further promoted by the global dimensions of many of the issues contemporary ethics is called on to address. Noting that the "who" doing ethics can begin from different standpoints is not to promote relativism so much as to deepen critical reflection.

In the West, ethics is commonly taken to be a key philosophic discipline—alongside logic, epistemology, metaphysics, political philosophy, and aesthetics. On closer examination, however, ethics can be seen to draw on many disciplines that have also emerged from it. Disciplines such as psychology and anthropology, as well as politics and economics, significantly contribute to ethics. Especially in its contemporary applied or practical versions,

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ethics is a hybrid of disciplinary concerns in, for example, biomedical ethics, environmental ethics, and computer ethics—each of which depends on multi- and cross-disciplinary interactions. Finally, ethics manifests strong transdisciplinary elements, insofar as it interacts with the life-world of social institutions and political orders. Informed by the development of multiple disciplines, implicated in the creation of hybrid research fields, and influenced by transdisciplinary concerns, ethics is a deeply interdisciplinary endeavor.

Outside the West there are many traditions of critical reflection on being human, often manifested in less strictly philosophical terms. But in the present chapter, we introduce only one non-Western perspective—that of China—because it is one of the most well developed and durable traditions of such reflection outside the European context and because of the increasingly global significance of Chinese culture. As with the historical overview of ethics in the West, however, our account of Chinese ethics is necessarily simplified and selective.

18.2 Historical Schema: Ethics in the West

At its origins, Greek *philosophia* referred to all learning and was thus inherently interdisciplinary. Before the demarcation of disciplines, philosophy was initially predisciplinary. From this predisciplinary manifold, the pursuit of knowledge in the European tradition unfolded as a progressive spinning off of multiple specialized forms of learning. From philosophy came physics, astronomy, natural history or biology, and psychology—including all of what are now termed the human sciences and the humanities. All were once part of philosophy as found in the works of Plato, Aristotle, and their successors.

The emergence of moral theory or ethics as an explicit dimension of philosophy is coordinate with what social scientists term structural differentiation. Over the course of Western history, there has been a tendency to disaggregate many aspects of human culture that initially existed in synthetic unity. For instance, one distinctive feature of the period between 500 BCE and 500 CE among peoples inhabiting the Mediterranean region was a gradual movement to distinguish among law (νόμος/*nomos*), custom (ήθος/*ethos*), narrative story (μύθος/*mythos*), reason (λόγος/*logos*), and nature (φύσις/*phusis*). For Aristotle, *ethics* originated with comparative rational analysis of the diverse ends or goods pursued in custom. The goods of pleasure, honor, and knowledge (*Nicomachean Ethics* I,5), when examined in relationship to human nature (*Nicomachean Ethics* I,7), were placed in a rational hierarchy that could serve as a basis for evaluating law and political order (in the *Politics*). Once we have a rational understanding of the good, political order should be constructed to promote that good.

But the development of ethics was only one epistemic structural differentiation. Since the 1500s in Europe and North America, structural differentiations emerged in science (where physics, chemistry, geology, biology, and more became distinct forms of knowledge), then in industry (through the division of labor), in government (separation of powers), and in religion (multiple church denominations). This systole of differentiation in turn gave rise to a diastole of counterefforts in pursuit of relationships or interactions among the associated cognitive and sociocultural structures, thus constituting in broad if nonstandard terms multiple manifestations of interdisciplinarity: interdisciplinary research in science, team management in industry, nationalism and constitutional formation in the state, ecumenism in religion, and universal human rights in culture. Philosophy today must include a general effort to question and understand these differentiations and their countermovements. This is especially the case with that structural differentiation in philosophy known as ethics.

Interdisciplinarity in this extended, metaphorical sense in ethics complements the standard theoretical frameworks for analyzing morality. Most prominently and persistently, ethics in the West is defined by competing frameworks of virtue theory, deontology, and consequentialism. The first stresses the importance of perfecting human nature through character formation; the second, obligation to fundamental commands; the third, judgment in terms of action outcomes, with utilitarianism and its stress on avoiding pain and promoting pleasure or happiness being its most common version. In schematic form, however, each can also be attached to a distinctive interdisciplinary project.

The first took shape in the Mediterranean region in the centuries preceding the common era, in response to an urbanization that put distance between humans and nonhuman nature, while placing individuals into interactions that extended beyond individuals with whom they were immediately related. For thousands of years human interaction with humans had been almost solely with members of extended family relationships. Once people began to live in large, sedentary societies and to experience multiple one-off encounters across groups larger than tribes it became necessary, in order to share place and reduce violence, to establish nonkinship bases for order and trust. Efforts to address the challenge of cultivating nonkinship trust were manifest in the development of transtribal religious moralities, law, and ethics.

Greek ethics sought in the competitive contacts and contracts among artisans, traders, and those freed from necessity—rather than in the necessarily cooperative life of farming and the family—reasons for condemning socially destructive actions such as murdering, stealing, and lying. Socrates took philosophy down from the heavens and into the marketplaces to discover contract rationality (see *Crito* 51c–53a) as a basic way to mediate relationships between individuals and the state. In Plato's *Republic*, the master virtue of justice is conceived as giving each of the other cardinal virtues (courage, moderation, and practice-wisdom) their due place or evaluation, thereby creating order in a society of disciplinary class distinctions among producers, warriors, and rulers. In Greek and Roman ethics such rationality in morality and politics became known as natural law, but the nature involved was an all too human nature from below.

A second interdisciplinary ethics project emerged in conjunction with the Judeo-Christian-Islamic notion of divine revelation or law, especially as articulated in Christian theology. In revealed theology, divine or supernatural infusions of command and knowledge from above can be variously understood as relativizing human rationality or enclosing it. For St. Augustine, divine revelation reduced the importance of nature; the virtues of the ancients were no more than "shining vices." For St. Thomas Aquinas, the ethics of natural reason was simply confirmed by and enclosed in revelation; the rational virtues of courage, moderation, practice-wisdom, and justice were preparatory for the super-rational virtues of faith, hope, and love. The super-rational virtues are less virtues in any pagan sense than obligatory responses to divine commands from above.

A third formation of ethics as interdisciplinarity in the extended sense of mediating between different aspects of human experience explicitly opposed the handmaid to theology project. In the modern period in the West, ethics functions instead as complement to a new kind of science, modern natural science—a science that methodologically rejects revelation and even the idea of god. During the Enlightenment, ethics became an interdisciplinary mediation, not so much between individuals and the state or between revelation and reason, as between the sociopolitical order and the pursuit of science in its new and distinctly modern form.

For both Greeks and Christians, human reason served as a normative foundation for ethics, either because of inherent goodness or as created by God. As nature became conceived in terms of a decomposition of forces and pursued for its use value, the new method was justified by an appeal to consequences. Francis Bacon promoted the scientific "conquest of nature" for the "relief of man's estate"; René Descartes proposed a science that would enable humans to become "masters and possessors of nature."

This version of interdisciplinarity in ethics argues for the autonomy of science and its support by the state because of its benefit to society. After World War II, Vannevar Bush justified state investments in science in terms of specific benefits in healthcare, economic development, and military defense. In another version, that of ethics as Romantic critique (see Mary Shelly's *Frankenstein*), it argues for delimitations on the method of decomposition in order to protect humans from dehumanization by science and technology. Criticisms of science and technology for contributions to environmental pollution, threatening democracy, or enhancing risk all continue to make consequentialist arguments. In both positive and negative cases, the consequences of science govern its ethical assessment.

In metaphorical terms, then, ethics as interdisciplinarity in the West has functioned to bridge or integrate (1) individuals and social orders through virtue ethics, (2) reason and revelation through deontology, and (3) science and politics in consequentialist utilitarianism. In the early twentieth century, however, efforts were made to construct an ethics purified of such forms of interdisciplinarity, in an analysis of ethics talk that came to be known as meta-ethics.

18.3 Historical Schema: Ethics in China

The Chinese term 伦理 (*lunli*), which is most commonly translated as "ethics," is composed of two characters. The first is cognate with a word meaning "human being" and refers to relationships between different generations; the second means inner principle or structure, from an original reference to jade carved according to its own textural structures. In China, traditional philosophy never differentiated ethics from other aspects of learning, and did not pursue differentiations to the extent found in the West. There are no classical Chinese works with *lunli* as a title. Ethics is less critical reflection on individual morality and more an effort to appreciate the inner principles of human inter-relationships in a harmoniously integrated world.

The most common way to compare China and the West is to take Western culture as normative and to describe China as lacking certain elements. As a heuristic exercise, however, a normative reversal can describe the West in terms of what it lacks with regard to common features of the Chinese tradition. First, Western ethics is weak in appreciating the ways humans are embedded in family relationships; instead it takes market individualism as a model for human interactions. Second, Western philosophy lacks the continuities, both historical and ontological, characteristic of Chinese philosophy; the West is full of breaks and oppositions, as in those between Greek and Christian philosophies and between (natural) earth and (transcendent) heaven. Third, the West lacks the ideals of harmony and complementarity that are fundamental to Chinese philosophy. Instead of the acceptance of differences, in which a person can be both mind and body or Confucian, Daoist, and Buddhist all at the same time, in the West people struggle with the mind-body problem and declare themselves as Jews, Christians, or Muslims.

Consider each of these distinctive features in slightly greater detail. First, what we call Chinese ethics originated with Kongzi (also known as Confucius). In the founding books of the Confucian tradition the leading ethical ideal is 仁 (*ren*), composed of condensed versions of the characters for "human" (人/*ren*) and "two or more" (二 / *er*), thus indicating affectivity among humans, and often translated as "benevolence." Like Socrates, Kongzi set aside concern with the gods in favor of a focus on human affairs (*Analects* 11.12), but in a more embedded sense than Socrates. The family and its inner structures play a central role in Confucian ethics, in which the relationships of ruler-subject, father-son, elder-younger brother, husband-wife, and friend-friend are presented as primary—and can be interpreted in the current context as providing another model for interdisciplinarity as family cooperation. (It is easy to de-gender the three central relationships to parent-child, elder-younger sibling, and spouse-spouse.)

Second, as is widely recognized, Chinese culture is the oldest living tradition in the world, with a continuity that dates back some 3,000 years. Central to this continuity is not just Confucianism but also the complementary traditions of Daoism and Buddhism. All three philosophical traditions aim not so much to develop systematic knowledge as to enrich this-worldly conduct by attending to more than just getting along with others on the practical level.

The continuities characteristic of Chinese ethics are both vertical (ontological) and horizontal (psychological). As the contemporary philosopher Li Zehou argues, a one-world ontology emphasizes integration of "mind and matter, soul and body, reason and emotion" (Li & Cauvel 2006, p. 24). Chinese heaven is nothing transcendent and in some contexts is equivalent to nature. It is the whole of which humans are a part, and the pursuit of harmony between parts and the whole can focus on coordinating relationships between humans and nonhuman reality, between individuals and social groups, or between humans and history.

There are many overlaps between ethics in China and in the West. For example, the notion of virtue is prominent in both traditions. But just as Western ethics has developed some ideas, such as deontology, that are hardly to be found in China, so there are elements of Chinese ethics, such as *wu-wei*, that are absent in the West. Especially in a chapter written primarily for readers in the West, it is reasonable to emphasize this distinctive notion of effortless action as an ethical standard to be found in the exercise of any virtue, as opposed to the virtues themselves, obedience to commands, or a calculation of consequences. Additionally, *wu-wei* serves as another ideal for interdisciplinarity. As the American Chinese scholar Edward Slingerland writes, in the most extended study of *wu-wei* in English, it represents "a perfection of a unique and ultimate skill . . . of becoming a fully realized human being and embodying the Way in the full range of one's actions" (Slingerland 2003, p. 9), combining inner integration and outward practical effectiveness.

Third, as in the West, Chinese ethics may be presented in broad-brush overview in terms of different interdisciplinary projects, but projects that are more *yin-yang* complementary than oppositional. In this regard, there are two aspects to *wu-wei*. In the one, *wu-wei* spontaneity involves living in harmony with the *dao* of nature or cosmos. Such is the ideal of Daoism. In another, the *dao* at issue is located in relationships among people as manifested in the good family or society. Confucian *wu-wei* is found in spontaneously acting as part of a family or larger group. *Wu-wei* and *dao* are at once features of natural and human orders. Virtue in Chinese ethics references more than being an effective "free man"; it involves accepting that humans are embedded in cosmic and social relationships without which their existence would not be possible. *Wu-wei* and virtue manifest an at-homeness in the world that is missing in the West.

In general terms, then, China adds to the metaphor of ethics as interdisciplinarity a bridging of aspects of human experience that enrolls virtue ethics (4) to harmonize humans with the cosmos and (5) to integrate the human inner and outer selves. However, in the mid-twentieth century a project that may be compared to the Western project of purifying ethics in the form of meta-ethics emerged in China: a Marxist effort to jettison Confucianism, Daoism, and Buddhism in favor of historical materialism. Remarkably, however, both efforts at purification—in the West and in China—have been creatively undermined by challenges from modern science and technology, promoting new registers of interdisciplinarity in the more literal sense.

18.4 Interdisciplinarity in Applied Ethics: Bioethics to Nuclear Ethics

In the West, the metaethics project aimed to set aside substantive debates about good and bad, right and wrong—and any presumptions to interdisciplinarity or application—by focusing instead on analyzing the meaning of moral terms and the structure of ethical discourse or argumentation. Influenced by the linguistic turn in philosophy, metaethics became an important dimension of linguistic philosophy as well as of linguistics itself. One key text was in fact titled *The Language of Morals* (Hare 1952).

According to the American philosopher Stephen Toulmin (1982), however, the practical problems created by scientific and technological advances in medicine "saved the life of ethics" in a more traditional, practice-relevant sense. He might have extended his insight to note that salvation involved resuscitation by interdisciplinarity as well. For Toulmin, when ethical reasoning became engaged in clinical work and considered the real-world practices of physicians, hospital ethics committees, and/or institutional or governance bodies, theoretical conflicts tended to be replaced with practical reasoning. Conflicts between deontology, consequentialism, and virtue ethics are sidestepped in favor of ad hoc constructions to deal with particular problems.

Such social consensus in the area of medicine on the basis of interdisciplinary ethical practice was further exemplified in the post–World War II creation of the Nuremberg Code for research on human subjects. While in earlier periods medical scientists had only weakly exercised their responsibilities for the protection of human subjects, Nazi concentration camp experiments revealed the need to develop universally agreed on protocols for the conduct of biomedical research. Judges from several nations consulted with medical experts to create protocols establishing applied ethical principles for technoscientific medicine. This transdisciplinary collaboration among legal experts and medical scientists resulted in foundational statements about the basic rights to free and informed consent for all medical research participants. Subsequent debates about human stem cell research, cloning, and the patenting of genomic sequences have continued to depend on broad cross-disciplinary dialogue regarding what factors and kinds of knowledge are relevant to biomedical research policy making.

Insofar as medicine engages with and is transformed by developments in the biological and life sciences, it becomes empirically interdisciplinary. This trajectory has turned medical ethics into the interdisciplinary fields of bioethics and biomedical ethics.

Responses to arguments by Toulmin and others have nevertheless made "applied ethics" a contested term. Yet regardless of the terms used to describe this domain—competitors include "practical ethics" and "professional ethics"—all affirm some form of engagement between and among multiple disciplines in doing ethics. Additionally, especially in the case of biomedical ethics, dialogue with cultures outside Europe can help clarify individualistic assumptions that often animate the West (see, e.g., Ten Have 2016).

Another example of how advances in science and technology have stimulated interdisciplinarity in ethics can be found in nuclear ethics: the ethics of nuclear weapons development and deployment as well as of nuclear power generation and production. In this case, the engagement spans the disciplines of nuclear science and engineering along with the politics and the health sciences. If such interdisciplinary engagements are to be fruitful, the particular issues posed for ethical analysis need from the beginning to be formulated through dialogue among the disciplines, so that the results of analysis are not predetermined by any set disciplinary concerns. To be effective, nuclear ethics reflection further requires international dialogue and political collaboration.

An additional distinctive feature of nuclear ethics, however, has been the practice of what Hans Jonas (1984) called the "heuristics of fear" and Jean-Pierre Dupuy (2002) terms "Enlightened doomsaying." The countermovement, of course, is technological utopianism, which is equally strong in the nuclear and in biomedical fields. Defenders of nuclear power, especially, often see it as the most viable alternative to hydrocarbon energy, while in the biomedical area transhumanists envision a future in which humans take control and overcome the limitations of their physical evolution. Again, such substantive ethical arguments will necessarily involve interdisciplinary engagements.

18.5 Interdisciplinarity in Applied Ethics: Environmental and Information Ethics

Related examples of applied ethics interdisciplinarity can be found in environmental ethics and computer or information ethics. Indeed, the development of environmental ethics was originally informed by nature writers (such as Henry David Thoreau and John Muir) as well as by conservation biologists (such as Aldo Leopold and Rachel Carson), all of whom undertook to advance critical ethical reflection on human–nature interactions from different disciplinary contexts.

In previous formations in the West, ethics had been concerned primarily with human-to-human or human-to-divine relationships. The wildlife biologist Leopold was the first to make the explicit case for an environmental extension of deontology to include what he called a "land ethic." In his words:

> All ethics so far evolved rest upon a single premise: that the individual is a member of a community of interdependent parts. His instincts prompt him to compete for his place in that community, but his ethics prompt him also to co-operate (perhaps in order that there may be a place to compete for). . . . The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively: the land. (Leopold 1949, p. 204)

Extending this notion of the foundation of an ethical relationship to encompass that of humans to the land required interdisciplinary collaboration to unpack its logic. Carson's more consequentialist research (1962) was instrumental in establishing a context for the creation of statutory laws and government agencies for protection of the natural environment. In turn, environmental protection has become a global discussion that now routinely engages politicians and economists on issues of sustainable development and climate change. In the twenty-first century, environmental ethics has developed into a broad interdisciplinary field that engages thinkers from the domains of literature, science, law, economics, public policy, education, and philosophy. In China, the Daoist tradition of concern for human–nature harmonies provides a further perspective relevant to environmental ethics.

The formation of computer and information ethics exhibits similar interactions. In the early stages scientists and engineers such as Norbert Wiener argued for directing ethical attention to the implication of the use of the new machines of data manipulation and communication. Wiener, the founding figure of cybernetics, titled his second book *The Human Use of Human Beings* (1950). From the beginning Wiener disparaged excessive specialization in science and sought to bridge the fields of mathematics, physics, engineering, and biology.

Complementing Wiener, the philosopher Luciano Floridi has argued that computer and information ethics requires integration with technical knowledge about information and computer technologies (ICTs). To promote this interdisciplinary ideal, Floridi has written books to educate philosophers about computers (1996) along with a general philosophy of information in which ethics forms a necessary part (2011). As Floridi argues in *Onlife Manifesto* (2014), ICTs are not so much tools as social forces that alter how we see ourselves, our social interactions, conceptions of reality, and understandings of agency. Across each alteration, ICTs engage ethical, legal, and political issues that we have only barely begun to appreciate.

Following the early work associated with Wiener, discussions in such professional technical societies as the Association for Computing Machinery (ACM), the largest nongovernmental organization of computer professionals, led in 1972 to formulation of a code of ethics in 1972. Other computer professional societies followed suit during the following decade: for example, the British Computer Society in 1983 and the Australian Computer Society in 1987. In 1978, interdisciplinary engagement between computer professionals and philosophers led to creation of the field of computer ethics and publication of a textbook of the same name (Johnson 1985). An explosion of interdisciplinary interest and collaboration followed among computer professionals, philosophers, social scientists, and others.

One substantive moral commitment that stands out in the interdisciplinary ACM code is an expressed respect for individual privacy. In the 1973 version of the code, this idea took the form of obligations to minimize personal data collection, to secure such data collections, and to arrange for the disposal of the data after appropriate use. In the 1992 revised code a similar respect for individual privacy is expressed as follows:

> Computing and communication technology enables the collection and exchange of personal information on a scale unprecedented in the history of civilization. . . . It is the responsibility of professionals to maintain the privacy and integrity of data describing individuals. . . . This imperative implies that only the necessary amount of personal information be collected in a system, that retention and disposal periods for that information be clearly defined and enforced, and that personal information gathered for a specific purpose not be used for other purposes without consent of the individual(s). (ACM Code, 1.7)

Most discussions about the ethics of information focus on the production side (of information or goods or solutions to problems) rather than on the use side, where consumers and citizens take up and use information, goods, or proposed solutions. Information production may be difficult to thematize, analyze, and practice interdisciplinarily. But interdisciplinary use of information is a quite common phenomenon: well and easily practiced if seldom theorized. Most "disciplinary" producers engage frequently in "interdisciplinary" consumption. When information producers leave the design shop or academic classroom they become citizens, members of families, churches, and users of all sorts of information goods and services—most of which they take up not as disciplinary experts or specialists but on the basis of commonsense experience.

To offer one example, the disciplinary historian becomes an inter- and transdisciplinary human when going to a healthcare provider. A physician's diagnosis and treatment recommendation is only incidentally filtered through the historian's perspective, insofar as questions might be asked about historical development and origin of a diagnosis or therapy. The historian qua patient and consumer of medical services has the ability and indeed the motivation to draw from any number of disciplines in the process of making sense of a diagnosis or a prescribed therapy: a general chemistry course from high school, a required science course in college, a novel about medical care, newspapers reports, and TV programs. Interdisciplinary consumption and use is a largely undertheorized aspect of interdisciplinarity that in fact functions in almost all areas of applied ethics—a fact that has been deftly elaborated as part of a critical theory of interdisciplinarity by Robert Frodeman (2014).

It is not clear, however, whether a rational interdisciplinary consumption of information can be practiced under conditions of the information explosion associated with a global Internet, big data, and the emerging Internet of things. A typically modern ideal such as privacy, for instance, appears increasingly crowded out by postmodern individualist celebrations of deprivacy (Mitcham 1997), state-sanctioned management and surveillance in the name of security, and data mining research for scientific, commercial, and military ends. Interdisciplinary responses may be impotent in the face of such historicocultural shifts. Thinking about these issues from multiple perspectives may mean that we never reach a decision from any one perspective.

18.6 Interdisciplinarity in the Professional Ethics of Engineers and Scientists

The disciplinarity found in modern material and cognitive productivity manifests a historically distinct character. In premodern periods, farmers, carpenters, and tailors were both producers and consumers of their own goods: Farmers ate the food they grew; carpenters lived in houses they built, and tailors wore garments they sewed. The concepts of natural philosophers accorded with common sense; the Ptolemaic model of the universe was confirmed by the rising and setting of the sun. The hyperstructural differentiation in assembly-line division of labor and the proliferation of knowledge disciplines with well-maintained boundaries that challenged perceptual experience led to explosions in both material and cognitive goods—but goods of which not even the producers themselves always had a good grasp.

As if to compensate for this disciplinary induced gap between producing and using, the semiautonomous technical professions of engineering and science collected themselves in meso-interdisciplinarity constellations. Civil, mechanical, chemical, electrical, electronic, industrial, nuclear, computer, biological, nano, and other engineers are all engineers. Physicists, chemists, and biologists are all scientists. Both meso-professional groups have formulated codes of professional conduct to guide their productivities in ways that contribute to better public usings.

Consider the case of engineering ethics. By the 1960s, professional engineering societies had, on the basis of their own internal interdisciplinarity work, adopted as paramount an obligation to protect public safety, health, and welfare—a commitment known as the paramountcy clause. Then in the 1970s, the US National Endowment for the Humanities (NEH) and the National Science Foundation (NSF)—stimulated in part by widespread transdisciplinary public concern about a series of engineering-related disasters (most prominently involving automobiles and airplanes) and in an effort to deepen understanding and practice the paramountcy clause—jointly awarded a number of grants to research teams of philosophers and engineers to study the ethics of engineering research and practice (Mitcham & Wang 2015). This resulted in the creation of a number of more macro-interdisciplinary team-taught engineering ethics courses and the publication of interdisciplinary engineering ethics textbooks (e.g., Martin & Schinzinger 1983; Harris et al. 1995).

A similar interdisciplinary dynamic has informed reflection and practice with regard to the ethics of scientific research. Stimulated again in part by transdisciplinary public concern—this time about fraud and misconduct in science, including the misuse of public funds—the NSF and the US National Institutes of Health (NIH) funded interdisciplinary research and course development on the responsible conduct of research (RCR). This trajectory was further promoted by interdisciplinary professional scientific organizations by the US National Academies of Science (NAS) and the American Association for the Advancement of Science (AAAS). A 1989 pamphlet, *On Being a Scientist*—produced by an interdisciplinary team—became a standard RCR teaching resource at both the graduate and undergraduate levels (Committee on Science, Engineering, and Public Policy 1989). This and related texts review basic research protocols regarding notions of integrity and honesty in the reporting of research results, the avoidance of conflicts of interest, the fair treatment of subordinates and colleagues, and respect for animal welfare for the purposes of raising awareness and fostering ethically responsible scientific practice.

In both engineering and science, however, the development of professional ethics also used interdisciplinary collaboration between technical professionals and philosophers to buttress technical disciplinary autonomy. Engineering and science as disciplines were defined not just in terms of design or experimental methods but also by ethical codes. From the technical professional perspective, ethics codes functioned to help engineers and scientists maintain their semiautonomous status in a world of "post-normal [engineering and] science" or "mode-2 [design and] knowledge production" in which research began to be assessed not just on the basis of intellectual merit but on broader impacts.

From the transdisciplinary perspective of society, however, professional ethics is not enough. In a globalized world increasingly dependent on and defined by science and technology, the professional ethics movement is too narrow and self-interested. A more robust transdisciplinary engagement is required between science, technology, and ethics. One such engagement began to be thematized in the second decade of the 2000s by European efforts to develop a concept of responsible research and innovation (RRI). As one European Commission policy entrepreneur defines it, RRI "is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)" (von Schomberg 2012, p. 48). One way to read the RRI initiative is as another interdisciplinarity effort to bridge the producing-using gap.

18.7 Applied Ethics Generalized

The recovery of practice ethics in the West, as a result of challenges from science and technology, has had an echo in China. Following the Reform and Opening that began in 1978, the Chinese Marxist effort to reject Confucianism, Daoism, and Buddhism in the name of historical materialism has eroded in favor of an effort to engage with the West and to rethink traditional Chinese ethics. In China, ethics has become part of a broad effort to assess and properly appropriate not just Western economics but also Western science and technology—and ethics. Indeed, there has been more explicit (and even government-sponsored) discussion of the ethics in relationship to science and technology in China than in any other advanced developing country such as Brazil, Russia, or India. There are units focused on ethics in the Chinese academies of science and of engineering and in the Ministry of Science and Technology, as well as in projects of research, teaching, and publication at a number of Chinese universities. Associated with such programs are further initiatives to reconsider especially the Confucian heritage.

The permutations of applied ethics in China as well as in the West display three common features. First, the distinctions between multi-, cross-, trans-, and interdisciplinarity are of marginal concern to those who practice interdisciplinary ethics. Interdisciplinary teams engage in their work and negotiate the parameters of their interactions on the fly, without much concern for theory.

Second, the *practice* of interdisciplinarity often remains transgressive. In the discipline of philosophy, for instance, those who become involved in interdisciplinary work can be professionally marginalized. Philosophers who specialize in applied ethics are not always accepted as equal members of their departments. They are sometimes nudged out of the discipline and into interdisciplinary units such as programs and departments of science, technology, and society (STS) studies. In this regard, Julie Thompson Klein has on numerous occasions described the character of interdisciplinarity that emerges in different institutional contexts as a consequence of the movement "out of the disciplines" by teachers, scholars, and researchers.

This results, third, in the formation of new questions about the professional and cultural boundaries of applied ethics work. Engaging in applied ethics in the context of contemporary globalization leads researchers to ask questions about the legitimacy of, for example, standards for RRI in Europe as distinct from the United States, China, India, or South Africa (European Commission 2009). In these cases globalization can be a contested issue. Is the European promotion of RRI a form of cultural imperialism or is it appropriately adaptable to Chinese characteristics? In China, interdisciplinary ethics functions as an aspect of globalization—a form of interdisciplinarity from which the West itself might learn.

Along with a number of distinctive substantive ethical ideals—for example, free and informed consent in bioethics, sustainability in environmental ethics, and privacy protection in computer ethics—two others are often incorporated into interdisciplinary ethics. One is that technical experts have the obligation to promote public education regarding the most relevant aspects of their work; another is that technical experts have an obligation to involve the public in decision-making about some technical matters. The additional two ideal commitments combine to co-responsible, interdisciplinary collaboration between the scientific community and the public (Mitcham 2003).

Any politics of technology further depends on cultivation of what may be called the technological imagination, a quality of mind that enables people to think with and through technology: negatively through doomsaying and positively through utopianism. This is equivalent to what Albert Borgmann calls "real ethics": an ethics that steps beyond ideas and theories and is more expansive than that focused on personal interactions. "Real means tangible; real ethics is taking responsibility for the tangible setting of life" (Borgmann 2006, p. 11). Real ethics recognizes how even as we design the world of artifacts within which we live, those artifacts design us. As Peter-Paul Verbeek (2014) argues, scientific technologies must be conceived as mediations and consciously designed as such.

18.8 An Interdisciplinary Future for Ethics

In broad-brush historical overview, allowing a metaphorical expansion of the term, interdisciplinarity in ethics has taken form to bridge (1) individuals and the state, (2) reason and revelation, (3) science and politics, (4) humans and nature, and (5) the inner and the outer in humans. More recently ethical challenges from science and technology have pushed interdisciplinarity into ethics in (6) a more literal sense: critically reflecting on the ways human actions are being transformed by science and technology. Such reflection requires interdisciplinary engagement with physicians, scientists, and engineers in both their knowledge and artifact production as well as with the national and international societal results of scientifically and engineered enhancements of knowing and making—as has been surveyed at length in *Ethics, Science, Engineering, and Technology: A Global Resource* (Holbrook & Mitcham 2015). Ethicists are learning to work with scientists and engineers, and scientists and engineers across the world are experiencing a need to learn from ethicists. Yet this interdisciplinary interaction has remained somewhat externalist, in the sense that ethics as a discipline has been left largely unaffected by science or technology, except insofar as it has tried to cope with and/or to become relevant to scientists, engineers, and the societal challenges their work generates. There are, however, opportunities for more internal interactions and engagements.

One scholar taking significant steps in this regard is the previously referenced Slingerland, whose work bridges West and East as well as science and ethics. Not only do ethics, science, technology, and engineering increasingly need to work together to deal with normative questions about the proper pursuit and use of scientific knowledge and technological power across cultural boundaries but also ethics itself can increasingly benefit from using science to sort through some of its own internal debates. The vitality of such use to inform ethical theory has been argued at length by Slingerland.

Slingerland originally studied classical Chinese philosophy and did extensive translation and interpretative work in primary Confucian texts. But since the late 1980s—influenced by George Lakoff and Mark Johnson's (1999) criticism of abstract rationality and arguments for embodied cognition—he has brought cognitive science to bear on ethical questions regarding the comparative adequacies of deontology, consequentialism, and virtue ethics, especially as debated among Chinese scholars. In Slingerland's view, "empirical evidence emerging from cognitive science, cognitive linguistics, social psychology, and primatology . . . calls seriously into question the . . . model of the self on which the two dominant approaches to ethics in the post-Enlightenment West, deontology and utilitarianism, rely" (Slingerland 2008, p. 306).

Although there are limits to what empirical scientific research can contribute to ethics (see Appiah 2008), there remains a good deal that ethics can learn from science. By exploring how the empirical results of cognitive and neuroscience confirm some of the Chinese ideas about *wu wei*, and how Chinese *wu wei* ideas can identify fruitful paths for future neuroscientific research, Slingerland offers a challenging model for the future of interdisciplinarity in ethics.

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An Ethics of Interdisciplinary Research

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I consider interdisciplinary research as a form of shift work. Unlike work shifts that begin and end with the punch clock, when there is a clear demarcation between the labor conducted in one domain (of work) and the next (nonwork), working in an interdisciplinary manner requires ongoing crossing of boundaries that are far from distinct or clearly demarcated. To push the notion of shift work further, the exciting contribution of interdisciplinary collaborations comes from its potential to shift the focus, practices, and paradigms that serve as the infrastructures of most institutions of higher education. Many studies of work in the university treat boundary crossing as the exception rather than the rule. Yet as the humanities scholar Julie Thompson Klein notes, "At this historical point, however, the interactions and reorganizations that boundary crossing creates are as central to the production and organization of knowledge as boundary formation and maintenance" (1996, p. 2). Yet it can be difficult to grasp the specific dynamics of this shift work across boundaries, let alone figure out how to exercise positive influence over it.

In once sense, academic shift work across boundaries is enabled by new technologies of communication, information storage and retrieval, and mobility. Shift work happens in blended classrooms, virtual galleries, online learning environments, mobile social spaces, and distributed cultural institutions. Our traditional brick-and-mortar spaces of cultural production and reproduction—research labs, art studios, universities, museums, libraries, galleries, and community centers—are themselves being transformed as participants engage and create new spaces of knowledge creation through the use-networked platforms and applications. While this work is differently influenced by new technologies, it is not strictly determined by networked applications, platforms, and spaces. Boundary-crossing is as much a matter of culture as it a technological phenomena. Remember that Baudrillard, in his analysis of the distinguishing characteristics of postmodernity, argued that where the modernist artist broke boundaries, the postmodern artist blurred them (Baudrillard, 1981).

In the service of elaborating an ethics of the practice of interdisciplinary research, scholarship, and teaching, I propose the following characteristics as a starting point for discussion (Balsamo, 2011). In doing so, I return to Klein's assertion that boundary-crossing is more common in the university than often noted. Moreover, the work of interdisciplinarity increasingly involves the collaboration among participants from distinct intellectual traditions, as well as institutional locations. Their successful navigation of differences (among collaborators) requires the fluid mutation of identities and affiliations. But this mutability is not easily accommodated within established institutions that govern and sanction knowledge production and that depend on specific structures, conventions, and often highly traditional rituals of production. In order to successfully navigate blurred boundaries as well as intellectually habituated ones, participants must be able to integrate and negotiate information that comes from different sources for the purposes of creating knowledge. To effect this, they must learn how knowledge is produced through dialogues among disciplines, through practices of social negotiation, and collaboration with peers and experts. Their knowledge-making activities will thus depend on understanding how disciplinarity functions as the institutionalized practice of knowledge verification.

The technohumanists Cathy Davidson and David Goldberg (2004) point out in their "Manifesto for the Humanities in a Technological Age," that those who call for interdisciplinary collaboration

(*cont.*)

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An Ethics of Interdisciplinary Research (cont.)

focused on applied social problems frequently disregard the participation of humanists. In one example they cite, Jeffrey Sachs, as director of the Earth Institute at Columbia University and special adviser to the United Nations secretary-general on the Millennium Development Goals, insisted "that interdisciplinarity was the only way to solve world problems" and proposed bringing together earth sciences, ecological sciences, engineering, public health, and social sciences with a heavy dose of economics. Humanists were left off the team. And yet it is obvious that complex social problems call for the design of hybrid solutions that benefit from the incorporation of intellectually nuanced cultural analyses and protocols of social implementation. Having called for a broader range of inclusion of disciplinary participants, it is important to note that those who collaborate as members of interdisciplinary research teams must resist any facile division of labor that relegates scientists to studying conditions and engineers to designing artifacts, with social scientists and humanists left to doing critique. While there are different roles to be played by different types of participants, all must be willing—indeed, eager—to learn new skills, analytical frameworks, methods, and practices. This is the starting point for a practical ethics of interdisciplinarity. When people with different disciplinary or even interdisciplinary backgrounds come together, it is important to acknowledge that everyone has something to contribute and to learn.

The following virtues describe the ethical commitments of interdisciplinary research:

1. *Intellectual generosity:* A genuine acknowledgment of others' work. This trait should be explicitly expressed to collaborators as well as mentioned via citation practices. Showing appreciation for other ideas in face-to-face dialogue and throughout a collaborative process also stimulates intellectual risk-taking and creativity.
2. *Intellectual confidence:* A belief that one has something important to contribute. Confidence avoids boastfulness and includes a commitment to accountability for the quality of a collaboration. Everyone's contribution to a collaboration needs to be reliable, rejecting shortcuts and guarding against intellectual laziness.
3. *Intellectual humility:* A recognition that one's knowledge is always partial and incomplete and can always be extended and revised by insights from others. This quality allows people to admit they do not know something without suffering loss of confidence or self-esteem.
4. *Intellectual flexibility:* The ability to change one's perspective, especially based on new insights from others. This trait can include a capacity for play, for suspending judgment and imagining other ways of being in the world and other worlds to be within.
5. *Intellectual integrity:* The habit of responsible participation. Such a habit serves as a basis for the development of trust, and is a quality that compels colleagues to bring their best work and thinking to collaborative efforts.

Beyond such particular virtues, however, development of a practical ethics of interdisciplinarity assumes that the exercise of these virtues will result in more nuanced and productive collaborations. In this sense, this discussion ultimately concerns the ethos of pragmatic interdisciplinarity, asking the key question of "how we make interdisciplinarity work better" in the service of formation of new knowledge, investigation of complex social problems, and creative invention of innovative technologies. While this discussion does not ask the many other questions under consideration in this volume—of whether interdisciplinarity *should* work or whether interdisciplinarity is *even possible* in the contemporary university—it does suggest that interdisciplinary work has the potential of instigating creative transformation of knowledge production practices adequate to understand our fluid and mutable futures.

Much interdisciplinary work is enabled by new technologies; much of it implicitly addresses issues about the relationship between technology and culture; much of it seeks to intervene productively in the cultures of knowledge production. In doing so, I suggest that this ethos of interdisciplinarity invites cultivation of what may be called the technological imagination, a quality of mind that enables people to think with and through technology, to transform what is known into what is possible (Balsamo 2011). The richer the technological imagination, the better the questions it will bring to the practices of interdisciplinarity. Facing uncertain futures, we might consider the possibility that knowledge is not "inter"-disciplinary, but more radically "un"-disciplined. This is equivalent to what Albert Borgmann calls "real ethics": an ethics that steps beyond ideas and theories and is more expansive than that focused on personal interactions. "Real means tangible; real ethics is taking responsibility for the tangible setting of life" (Borgmann 2006, p. 11). Real ethics rests on the recognition that even as we design the world of artifacts within which we live, those artifacts design us. For those now considered members of a generation "born digital" (who came to consciousness after the emergence of the Internet in the 1990s), daily life unfolds through the movement among different knowledge contexts. There is a transgressiveness that emerges from repeated experiences of traveling across linked information flows. Successful navigation of media flows, distributed learning, and social environments requires a fluid mutation of interests, identities, and affiliations. Mutability is not only a necessary attribute in a world of blurred boundaries and shifting contexts but also the foundation for a lifetime of learning. Those committed to interdisciplinary practices of teaching, creative production, and research would do well to embrace mutability as the "tangible setting of life." This is the scene for the practice of the ethics of interdisciplinarity.

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PART IV

CROSSCUTTING AND INTEGRATING PERSPECTIVES

CHAPTER 19

INTERDISCIPLINARY LEARNING

A Cognitive-Epistemological Foundation

VERONICA BOIX MANSILLA

> With the Vietnam Veterans memorial, I needed to ask myself the question "what is the purpose for a war memorial at the close of the twentieth century?" . . . Perhaps it was the empathic idea about war that led me to cut open the earth, an initial violence that heals in time but leaves a memory—like a scar.
>
> —Maya Lin, *Boundaries*, 2000

> A more robust understanding of human-resource interactions is needed to strengthen theories about collective action and sustainable governance. . . . [For instance, in Ecuador] trust, communication, and social obligation depend on social histories of resource systems and types of collective action problems, largely explaining why local institutions encourage individuals to uphold mangrove forest conservation but have little effect on cooperation in fisheries.
>
> Christine Beitl, *World Development*, 2013

19.1 Introduction

Preparing individuals to lead informed and fulfilling lives in dynamic knowledge societies requires that we nurture synthesizing minds. We must nurture individuals' capacity to knit knowledge from vast and disparate sources together into coherent wholes in order to address pressing issues of cultural and natural survival (Gardner 2006). Synthesis is a fundamental human capacity. It manifests early in life, when children engage in symbolic play, create artistic compositions, or learn the rules of a new game. To a certain extent, we learn to synthesize rather effortlessly by participating in societies where analogies, rich visual representations, and simple systems are ubiquitous. *Interdisciplinary* synthesis, however, presents heightened cognitive demands and requires deliberate instruction. It implies the

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integration of knowledge and modes of thinking in two or more disciplines in search for better understanding. Understanding how individuals learn to integrate different forms of expertise to create a work of art, explain a multifaceted phenomenon, fashion a new technology, or propose a sustainable environmental solution is essential if we are to cultivate this capacity among collegiate and precollegiate youth. What cognitive processes are central to interdisciplinary integration? What kind of "knowing" is embodied in a historical monument, an explanation of overfishing, or a sustainable development policy? On what basis can we discern the relative success of such form of integrative cognition? Ultimately, how can we design instruction to nurture potent forms of interdisciplinary integration?

Characterizing interdisciplinary integration is complicated by the vast and diverse array of intellectual endeavors the term denotes (Frodeman 2010; Klein 2010). Maya Lin's Vietnam Veterans Memorial in Washington, DC, departs from traditional monument architecture by presenting visitors with two granite walls forming an angle below ground level and in open air. Lin describes her creation as a "scar." Her metaphor frames the war experience in terms of a country divided in need of healing. Detailed analysis of war casualties records gives room to long lists of individual soldiers' names chronologically engraved on reflective granite. As visitors see their own image on the wall, living selves and lost others meet and reconcile—art and history intertwine to illuminate human experience past and present.

Her integration differs greatly from that of environmental economists interested in explaining the conditions that will prompt a community to act to protect natural resources at a short-term cost. This work weaves together factors such as a community's social cohesion, levels of trust, communication, and social obligation as well as biological ecosystems features into a complex causal explanation of why coastal inhabitants in one region may succeed in organizing to conserve mangrove forests but not to limit overextraction practices (Beitl 2014). In this integration individual factors typically studied by sociologists, anthropologists, and biologists complement one another to maximize explanatory power. This example differs from Lin's with respect to its aim, contexts, the kinds of data, theories and approaches they integrate, and the key cognitive processes involved in integration—that is, a complex explanation here and a metaphor before.

Today, interdisciplinary pronouncements are prominently featured in university mission statements—and capital campaigns—the world over. Understanding how people learn to synthesize is essential, if we are to design quality instruction and support learners to fulfill these institutional aspirations. Because syntheses vary, we must investigate the epistemological foundations on which learning to synthesize stands, and attend to the common *and* idiosyncratic features of interdisciplinary syntheses and the concomitant criteria by which we might deem them acceptable (Boix Mansilla 2002). Yet we know little, empirically speaking, about the cognitive mechanisms or the epistemological foundations on which a memorial or a sustainability explanation can be deemed an interdisciplinary learning achievement. Seeking to address this gap, this chapter examines interdisciplinary learning in cognitive and epistemological terms. Section 19.2 focuses on learning processes, beginning with "interdisciplinary integration" as a key, albeit polymorphous, aspect of interdisciplinary learning. Section 19.3 turns to the foundation of interdisciplinary learning and proposes an epistemological approach to characterize the foundations of interdisciplinary cognition. Section 19.4 illustrates the proposed approach by revisiting the opening examples. In conclusion, the chapter outlines the implications for instruction that come from this approach.

19.2 Learning to Integrate: Cognitive Approaches

Among scholars of interdisciplinarity, "integration" stands as the philosophers' stone of interdisciplinary efforts, capable of turning diffuse disciplinary insights into valuable understandings. "Integration" distinguishes "disciplinary" and "multidisciplinary" practices from "interdisciplinary" ones. The construct has proven malleable enough to include stakeholders' expertise in "transdisciplinary" work. A focus on "integration" as central to interdisciplinary activity has earned some scholars the title of "integrationists" (O'Rourke et al. 2015). And yet scholars differ in whether integration is the aim of interdisciplinary work, or a means to deeper understanding; the result of a stepwise algorithmic process, or a heuristic and iterative effort; a mostly cognitive, or a socio-communicative-cognitive phenomenon.

Characterizing the cognitive processes involved in interdisciplinary integration has proven difficult on multiple grounds: First, interdisciplinary synthesis can only be observed through manifest communicative efforts (a reflection on a work of art or a written explanatory paper). Second, integration is not merely the endpoint nor the ultimate purpose of interdisciplinary inquiry, but rather is embedded in complex, often-circuitous investigative processes (Holbrook 2013). Integration in research and learning occurs throughout a given inquiry process—that is, when describing a problem to be understood, formulating questions, creating theoretical frameworks, combining methods, selecting instrumentation, and deploying analytical categories or when gauging the contribution of an interdisciplinary approach (Bergmann et al. 2012). Third, and perhaps most importantly, interdisciplinary synthesis embodies a vast array of purposes and disciplinary combinations. It demands a characterization that sheds light on common cognitive processes while respecting the idiosyncrasies of particular disciplinary crossroads. Faced with the complexity of interdisciplinary synthesis as a construct, it is perhaps not surprising that cognitive studies of interdisciplinary learning are scarce.

Cognitive psychologists have documented domain-specific learning processes and progressions in mathematics, biology, physics, and history, among other fields. They have also identified foundational learning principles across domains:

1. Learners enter learning with prior "theories" about the topic under study. Typically invisible, these theories frame and give meaning to new information.
2. Learning is robust when knowledge is organized around higher order concepts and frameworks that facilitate retrieval and transfer.
3. Such learning pivots on metacognitive processes whereby learners take control of their learning, setting aims and monitoring progress (Bransford et al. 2000).

"Deep learning" involves the capacity for "transfer," that is, the ability to use newly learned information in a novel situation. Learning principles and quality markers of this kind provide a strong generic foundation for interdisciplinary cognition.

Interdisciplinary learning has been linked to sophisticated conceptions of knowledge, learning and inquiry, and heightened learner motivation and engagement (Baxter & King 2004). In fact, interdisciplinary learning involves relatively well-studied processes that operate in and across disciplines such as evidence-based reasoning, complex causal thinking, temporal and spatial representations, and critical argumentation. However, unique to interdisciplinary learning is the fact that these processes *integrate* information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines, typically in order to craft products, explain phenomena, or solve problems, in ways that would have been unlikely through single disciplinary means (Boix Mansilla 2002). How do learners produce such hybrid and informative advancements in understanding?

Available studies of interdisciplinary learning build more or less explicitly on various intellectual traditions. For instance, neo-Piagetians invoke learning progressions in loose, stage-like phases explained by an individual's growing information-processing capacity—specifically, the capacity to operate at increasing levels of complexity and logical abstraction. From this standpoint, the integration of two concepts builds on the more particular understanding of each concept in isolation. Higher order concepts such as "systems" or "systems of systems" organize lower order ones rendering such abstractions a desirable mark of learning success (Fischer Zheng, 2014). Applied to interdisciplinary learning, this approach proposes that individuals learn isolated concepts and sets of concepts in isolated disciplines first. Only later, the approach implies, are learners able to integrate knowledge from two disciplines around a central and more abstract theme. Ultimately, it is proposed, learners build an overarching knowledge structure of further complexity and abstraction that can be applied to new interdisciplinary themes (Ivanitskaya et al. 2002).

In contrast, conceptual blending theorists (Fauconnier & Turner 2002) locate synthesis in our capacity to combine two existing concepts into a new unit of meaning. Blended concepts such as "problem-solving" or "hand-writing" are pervasive in everyday language. Miller (2005) showed how compound concepts (e.g., *empirical bioethics*) and concepts of expanded meaning (e.g., *innovation* in evolution, cell development, technology, and organizations) enabled individuals to integrate disparate bodies of information. Star and Griesemer (1989) on their part coined the notion of "boundary objects" to describe shared foci of knowledge—plastic enough to be interpreted differently by different actors, yet robust enough to maintain unity across contexts. Similarly, Bromme highlights the construction of common ground—a shared definition of a problem or approach—as an interdisciplinary learning achievement (Bromme 1999).

Considering cognitive development as culturally situated (Vygotsky 1978), some scholars examined progressive appropriations of disciplinary discourses and modes of thinking among individuals trained in different fields. Collins and Evans propose "interactional expertise"—that is, the capacity to bridge "distinct [disciplinary] practices through a deep sharing of discourse" (Collins & Evans 2007, p. 53; Collins et al. 2010) as an interdisciplinary learning achievement. It enables members of distinct disciplinary cultures to participate in productive conversations while still not reaching "contributory expertise." In turn, studies of social cognition and distributed expertise also show how cognitive apprenticeships, such as collaborations in teaching, enable experts to learn intellectual practices in neighboring domains (e.g., analysis styles, disciplinary languages) essential for interdisciplinary exchange (Derry et al. 1998).

As the examples above reveal, available empirical studies shed a partial and fragmented light on interdisciplinary cognition. For instance, a neo-Piagetian commitment to *information processing, complexity*, and *logical abstraction* operates well when systems analysis is the approach of choice to address a given problem. It fails to shed light on other intellectual goals such as creating a beautiful art experience or crafting a workable technology. An emphasis on *boundary* and *blended concepts* sharpens our focus on a key cognitive tool for integration but calls for further study on how such concepts function at different disciplinary intersections as well as the cognitive processes that make them possible. A focus on *distributed expertise* points to the potentially complementary information held by members of a group, yet further studies need to show how individuals negotiate meaning across varied disciplinary boundaries over time. At the heart of the matter stands the question of what kind of entity interdisciplinary integration is—a well-founded abstraction, a compound concept, a social exchange—and the kind of knowledge or insight it is expected to yield in the cacophonous world of disciplinary specializations. A more integrated view of interdisciplinary cognition demands a discerning and encompassing epistemological foundation.

19.3 Epistemological Foundations of Interdisciplinary Learning

Theories about learning embody ideas about the very content being learned—for example, logical abstractions, distributed representations. Understanding how people learn to create an aesthetic interpretation of past events or to explain human responses to overfishing also invites an epistemological reflection about the nature of interdisciplinary knowledge. Epistemological theories seek to shed light on the nature, justification, limits, and, in some cases, the utility of knowledge and beliefs. Theories differ, however, in the way they characterize the landscape of human knowledge, the relative significance they attribute to particular knowledge forms, and the standards and criteria by which knowledge is deemed acceptable (Elgin, 1997). As a result, epistemological frameworks also differ in their utility to shed light on interdisciplinary knowledge integration.

For more than a century, for instance, philosophers of science have advanced various articulations of a "unified theory of knowledge" seeking to distill underlying principles across apparently disconnected disciplines. From early twentieth-century logical positivism to today's complexity theories, Wolfram's computable knowledge, and E. O Wilson's consilience, proponents of unity of knowledge theories have deemed their approaches foundational in providing a platform for interdisciplinary work. Each theory has privileged a specific knowledge form (e.g., propositional knowledge, computational algorithms, or biological principles) as the primary guarantee of credibility and the standard by which to deem explanations satisfactory. Yet they have done so at a cost. These perspectives on knowledge restrict the kinds of phenomena they seek to understand to those that can be interpreted in their preferred knowledge form, thus excluding important human cognitive achievements, especially in the realms of art and normative or moral reasoning (Goodman 1976, 1978).

Confronted with interdisciplinary phenomena such as the creation of Maya Lin's Vietnam War Veterans Memorial, a sole emphasis on propositional knowledge, computational algorithms, or biological principles falls short. Epistemologically speaking, these views of knowledge are unable to make sense of Lin's aesthetic experience in its own right. They remain silent about her visually nuanced interpretation of the past. Too complex and uncertain to be encoded in a system of irrefutable premises and logic, too semantically dense for modeling and verification, too resistant to being reduced to an adaptive biological achievement, the monument falls outside the purview of early positivists and more recent theorists of knowledge unity.

Similarly, confronted with the challenge of explaining how a community responds to overfishing, knowledge assumptions underlying unity of knowledge efforts are likely to reduce the problem's richness and complexity to the favored epistemic form. The limitations that early positivist or contemporary unity of knowledge approaches face do not fully invalidate their commitment to derive the best algorithm to model a complex phenomenon or a key biological principle to account for human behavior. Rather, they reveal the boundaries of these approaches' applicability.

Interdisciplinary pursuits are diverse, and substantive cognitive transfer across tasks can rarely be expected. Expertise in memorial art does not correlate with a heightened capacity to explain socioenvironmental phenomena. Against this background, what constitutes a productive epistemological framework for interdisciplinary learning? Four principles must be considered: First, a fertile framework must be *pluralist* in its capacity to account for multiple forms of disciplinary understanding on their own terms and embrace various intellectual agendas. Second, it must be *relevant* to the phenomenon of interdisciplinary learning illuminating the processes of interdisciplinary integration. Third, the framework must *explain* how knowledge advances from less to more accomplished instantiations shedding light on the essential dynamics of learning. Finally, it must offer some form of *knowledge quality assurance*—an epistemic mechanism that diminishes the likelihood of error by putting forth robust and relevant standards of acceptability across interdisciplinary endeavors.

To shed light on knowledge integration in interdisciplinary learning, an epistemological theory must neither limit its reach to the realm of empirically validated propositions nor reduce all forms of knowledge to a privileged one, such as logic, mathematics, or biology. Such emphases, as we have seen, constrain the types of interdisciplinary learning these theories can legitimately examine. Instead, a productive epistemology offers insight into how understanding of a subject matter can be advanced, whether such understanding entails an aesthetic interpretation of the Vietnam War or a comprehensive explanation of overfishing practices. Relevant to interdisciplinary learning is an epistemology that sheds light on how humans can make increasing and better sense of the world, themselves, and others through the integration of available disciplinary insights.

19.4 Toward a Dynamic View of Interdisciplinary Learning

The criteria for an epistemology of interdisciplinary learning established above point directly to *pragmatic constructionism*—the epistemological foundation for interdisciplinary learning here proposed. With roots in the work of the philosophers Nelson Goodman and Catherine Elgin, this approach offers a suitable frame to characterize interdisciplinary learning that is purposeful, pluralistic, and provisional (Goodman & Elgin 1988). As constructionist, this epistemological framework posits that the purpose of inquiry (and in this case learning) is not necessarily the certification or acquisition of "true" knowledge claims, but the advancement of understanding. Inquiry is not the accumulation of propositional knowledge in the search for certifiable truths. Rather, it seeks a broad, deep, and revisable understanding of its subject matter. Taking a pragmatist stance, the proposed epistemology puts a premium on the purpose of inquiry—to create an insightful work of art, explain a sociobiological system, or advance an effective policy. Within this view, understanding can embody multiple forms (aesthetic, analytical, interpersonal, ethical understanding) and materialize in multiple symbol systems (mathematical, visual, linguistic, kinesthetic). As such this epistemology is fundamentally pluralistic.

Ultimately, understanding involves the construction of what Elgin describes as "a system of thought in reflective equilibrium." A system of thought is in reflective equilibrium when its components are reasonable in light of one another and the account they constitute is reasonable in light of our antecedent convictions about the subject at hand. Such a system, Elgin notes, affords no guarantees. It is rationally acceptable not because it is certainly true but because it is reasonable in its given epistemic circumstances (Elgin 1996, p. ix). Building and validating understanding involves a series of delicate adjustments by which new insights are weighed against one another and against antecedent understandings of the subject matter. A conclusion is deemed acceptable not through a linear source of argumentation but through a host of sources of evidence, which include findings, statements, and observations as well as useful analogies, telling metaphors, and powerful exemplifications. Evidence might not precisely "match up," but might still paint a telling picture that helps us advance our understanding of the subject, all things considered.

Within the epistemological framework here proposed—that is, a pragmatic constructionism centered on purposeful, pluralist, and provisional understandings—the acceptability of a knowledge system is to be measured against the purposes of inquiry that guide its production. Multiple forms of integration are recognized and their justification is also provisional. In Elgin's view, considered judgment recognizes the unfortunate propensity for error of the human mind and adapts to it by demanding corrigibility. This epistemology demands that we be prepared to criticize, revise, reinterpret, and abandon intellectual commitments when more reasonable ones are conceived.

The implications of pragmatic constructionism for a theory of interdisciplinary learning are potent. By shifting our attention from accumulation of propositional knowledge (or the search of ever encompassing systems of systems) toward a deep and broad understanding, the proposed epistemology recognizes—as does learning science—that prior knowledge matters in the ways in which individuals make sense of the world. Prior knowledge informs questions, affords hypotheses, and provides an initial representation of a problem under study. By broadening the admissible sources of knowledge and inquiry beyond strictly certified propositions, this pluralist epistemology invites the inclusion of other symbol systems (visual, musical, kinesthetic) and ways of knowing such as artistic interpretations or literary fictions, including a learners' naïve or indigenous beliefs. Interdisciplinary understanding can thus be viewed as a "system of thought in reflective equilibrium"—a complex and dynamic set of connections and mental representations that embody insights and tensions across disciplines, represent an improvement over prior beliefs, and remain open for review.

Emerging is a dynamic and cognitively aligned picture of interdisciplinary integration (see Figure 19.1). Accordingly, four core processes are involved in dynamic interaction: (1) establishing purpose; (2) weighing disciplinary insights; (3) building leveraging integrations, and

(4) maintaining a critical stance. In interdisciplinary learning, such processes interact dynamically, informing one another as learning progresses iteratively. The result is a system of thought in reflective equilibrium—an improvement in understanding subject to further revision.

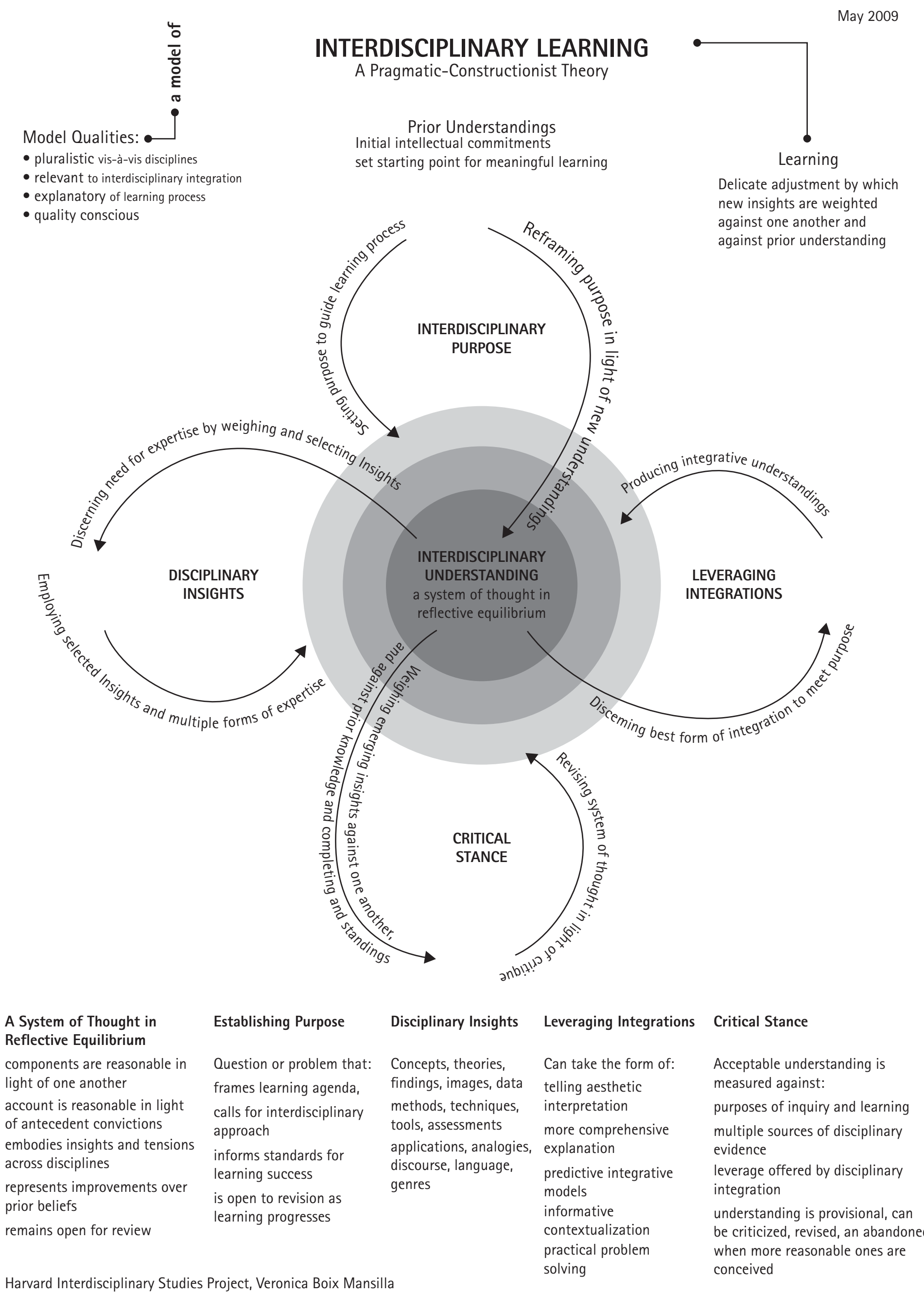

FIGURE 19.1 Interdisciplinary learning as a dynamic system of thought in reflective equilibrium.

19.5 Learning to Create Memorials

How does learning unfold at the dynamic intersection of two or more disciplines? To illustrate how the proposed view of interdisciplinary learning functions,we revisit our opening examples next.

19.5.1 Establishing Purpose

The purpose of a monument is to commemorate the memorable, to make past experiences part of our present. Memorials—a particular kind of monument—offer a special precinct, a segregated place where we come to honor the dead and reflect about past, present, and future (Danto 1991). To establish her purpose, Lin works iteratively, seeking to re-represent the past aesthetically to invite a reflection about war and reconciliation. The success of her interdisciplinary learning is thus best measured by the monument's effectiveness and her reflections about it, rather than by he monument's capacity to explain the Vietnam War, nor the level of abstraction and systematicity of her vision (goals she did not pursue). Similarly, when students learn to create a monument, clarity about purpose enables them to determine the focus and scope of their investigation, find intrinsic meaning in their efforts, and set parameters for success. What is the purpose of your monument? What are you hoping it will help people understand? What might a successful monument look like? Questions of this kind can orient learners as they embark in their learning journey.

19.5.2 Weighing Disciplinary Insights

Throughout her investigation, Lin construes successive and revisable systems of thought in reflective equilibrium—tenable and iterative representations of the memorial idea and execution. In doing so, she must work with disciplinary ideas, weigh them against her present understanding, and assess their role in informing the whole. For instance, Lin must distill the historical significance of the Vietnam War—a relevant story to be told through art. At the same time, she must weigh aesthetic options regarding symbolism and materials. In learning to create a historical monument less seasoned learners must do the same.

The domain-specific cognitive demands are not minor. Shorn of research experience in history, even postadolescents tend to view significance as an intrinsic quality of events, not one attributed to them in light of their consequences or shifting interests in present societies. Similarly, learners may construe historical accounts as stories unproblematically pasted together from literal interpretation of primary sources. In fact, historical accounts are constrained by historians' choices of perspective (political leaders, antiwar youth), time frame (the Tet Offensive vs. the Cold War), and forms of explanation (individual triggers or long-standing cultural forces). The learner must, through considered judgment, decide on a representation of the past that will inform her monument productively. Educators may ask: What does the historical record tell us about what happened during the war? What is the powerful story to be told about this period? What is special or unique about this particular war? What are the stories worth telling to the audience you have in mind?

The arts too impose cognitive demands. The artist must envision detailed versions of the monument in her mind; consider competing materials, techniques, and provocative symbolisms. She will need to think aesthetically, move beyond naïvely privileging "decorative" beauty, commit to multiple interpretations, some intended, some emerging. Here too the learner weighs options through an iterative interaction that must keep Vietnam and the purpose of the monument in mind. What aesthetic tools, materials, or images can help you create the experience you seek to create? How does an artist think about this War? What is the value added of an aesthetic lens and what would be lost if the arts were not included?

19.5.3 Building Leveraging Integrations

Interdisciplinary learning yields a system of thought in reflective equilibrium typically organized around a preferred form of disciplinary integration. Throughout the learning process leveraging integrations are assessed, considered, revised. Learning to create a historical monument involves learning to reframe a significant past in terms of visual metaphors that drive the aesthetic design of a piece. In Lin's work, the devastating consequence of the Vietnam War on the individual minds and social cohesion of American society is represented as a scar—a cut in the earth to be healed by time. Supporting learners to produce telling aesthetic syntheses requires some understanding of how the mind constructs metaphors.

Metaphors frame reality in terms of similarities between constructs pertaining to different realms. In them, a vehicle concept (e.g., the scar) highlights certain features of the topic one (e.g., the consequences of war), while obscuring others (Goodman 1976). Framing the Vietnam War as a scar sheds light on the personal emotional experience of war and its long-lasting impact. It does not illuminate the military actions or political conundrum surrounding the war. Visual thinking metaphors create a holistic synthesis and operate in a physical medium—in this case, the landscape, the stone, and the engravings (Arnheim 1966; Bruner 1986).

Learning to interpret and produce metaphors of this kind imposes important challenges on the developing mind. Early in life children can make sense of metaphors based on concrete similarities "the wrinkled apple is an old lady." However, the sophisticated interdisciplinary synthesis of the Vietnam War as a scar requires that learners understand the issue well enough to establish an adequate analogy between vehicle and topic. To create a telling metaphor about the past—in other words, a leveraging integration—learners must assess initially tenable metaphors for their capacity to portray essential aspects of the past accurately, to lend themselves to powerful visual representations and to maximize the likelihood that the overall purposes of commemoration, healing, and reconciliation are served. A workable metaphor stands in delicate tension among these three forces: historical accuracy, visual generativity, and power to heal. In other words, the metaphor stands in a system of thought in reflective equilibrium.

19.5.4 Maintaining a Critical Stance

Understanding is endless and cyclical. Our informed conclusions about a topic are challenged by novel contexts, insights, and experiences. A pragmatic constructionist epistemology draws its strength not from the attainment of final infallible truths but from the recognition of the limitations of our knowledge. Understanding must stand the test of competing interpretations of the subject matter. Meta-cognition—the capacity to reflect about the nature of ones knowledge, learning, and thinking—correlates with understanding preparedness for independent learning. In interdisciplinary work, navigating multiple knowledge landscapes demands a meta-cognitive—and often a meta-disciplinary—stance.

In Lin's example, her understanding of the long-lasting process of healing after Vietnam is enriched by an awareness of the limits in her interpretation—the many Vietnamese lives that were not engraved in her design. Such limitations often function as a pathway toward revising one's understanding, calibrating one's purpose or including new disciplinary insights toward the construction of yet a new and improved system of thought in reflective equilibrium.

19.6 Explaining a Community's Response to Overfishing

Clearly not all interdisciplinary integrations seek an aesthetic synthesis. Students of socioenvironmental systems seek to advance our understanding of phenomena that live at the intersection of humans and their natural environment (Palmer 2015). For example, to explain the conditions that enable a given community to self-organize to avert a critical depletion of their natural ecosystems, the environmental anthropologist Christine Beilt asks, to what degree do community members assess the expected benefits of managing a resource against the perceived costs of investing in better management practices? How are such benefits—economic, social, identiary—perceived? What role does the nature of the environmental problem (e.g., mangroves conservation vs. cockle fishery extraction) play in making action possible?

19.6.1 Establishing Purpose

Beilt's purpose is to advance a complex explanation of the social and environmental factors underlying collective action. Hers is not a contemporary art interpretation of environmental fragility geared to provoke and feed the imagination in the style of David Buckman's series on ice and climate change (Buckman 2012). Rather, she seeks to advance an empirically grounded and illuminating explanation of the conditions that lead local fishing communities in Ecuador to participate in the protection of mangrove forests that are at risk of being transformed into shrimp farms, while disregarding policy limits on the harvesting of small shells essential to fishery regeneration. It is against the background of this explanatory aim that Beilt's interdisciplinary success should be assessed. Learning to synthesize demands an analogous clarity of purpose. Purpose is iteratively constructed and progressively clarified through the dynamic calibration of prior understanding of the subject matter, inquiry interests, and practical considerations of viability. When articulating the intrinsic purpose of their synthesis efforts, learners also establish the epistemic form—that is, a complex explanation coupled to a practical policy solution—on which their synthesis will stand as a system of thought in reflective equilibrium.

19.6.2 Weighing Disciplinary Insights

In advancing their explanations of socioenvironmental systems, researchers and learners can draw on a broad repertoire of factors, typically studied in economics, sociology and anthropology, physical sciences, chemistry, and biology. Disciplinary contributions vary, as do the specific combinations of disciplinary perspectives relevant to address a given question. Disciplines embody distinct sensitivities about what matters most to study, preferred units of analysis, available theories, methods, data, and discourses as well as about what counts as a satisfactory explanation. Understanding how marine ecosystems might set conditions for collective action implies considering factors such as an ecosystem's size, boundaries, and fish mobility as well as equilibrium, resilience, and growth—typically studies by ecologists. Yet because a community's propensity to self-organize is mediated by its members' understanding of the issue at hand, a more satisfactory understanding the problem would need to include fishermen's perceptions of their changing environment, typically revealed through ethnographic case studies, interviews, focus groups, and observations characteristic of anthropology. Advancing a plausible and satisfactory explanation demands that learners weigh the explanatory contributions of various disciplinary insights. Experts tend to identify key insights in disciplines other than their own through interactions with peers. Among less experienced learners, weighing disciplinary contributions often requires deliberate guidance. Not all disciplines will prove equally relevant to an explanatory model, nor will the individual findings, theories, or methods provided by a selected discipline.

19.6.3 Building Leveraging Integrations

Synthesis unfolds throughout the learning process as explanations of collective action are advanced and revised. Explaining collective action is a demanding task for learners who must come to think in complex causal terms. Since early in life, learners are prone to linear explanations in which causes and consequences stand in temporal and spatial proximity (Perkins & Grotzer 2005). Only through careful instruction do learners advance explanations rooted in multiple mechanisms and agents. For example, they find difficulties understanding reciprocal causality whereby causes and consequences intertwine in feedback loops. Learners may fail to see that loss of available fish contributes to poverty and heightened social vulnerability, which in turn deters community members from privileging long-term sustainable environmental and economic gains over the satisfaction of their immediate needs. In building complex explanations, learners are challenged to connect factors that stem from different disciplines and are distant in time and space. They face the challenges of understanding multiple nonlinear causal mechanisms such as the emergent demands on fisheries caused by population growth and growing demands for protein around the world. Efforts to integrate are likely to generate new questions that lead them return to a disciplinary inquiry and back.

19.6.4 Maintaining a Critical Stance

An explanatory system of thought in reflective equilibrium integrates these direct and indirect causes into a complex account of collective action. It does so through a back-and-forth process of calibration. In this process, learning aims, disciplinary contributions, and synthesis iterations are weighted, coordinated, and advanced. Yet a pragmatic constructionist epistemology also suggests that understanding collective action in the mangroves of Ecuador demands that learners remain critical of their emerging conclusion. Important factors may have been missed, the evidence used holds varying levels of confidence, and future developments may call for revisions in the account proposed. In sum, interdisciplinary learning as here conceived involves more than recording information about collective action. Rather it embodies a pragmatic process of weaving together perspectives that contribute to a richer understanding whose standards of acceptability are constructed and driven by the purpose of learning, intrinsically conceived.

19.7 Conclusion

This chapter advances an epistemologically grounded view of interdisciplinary learning that foregrounds the construction of purpose-driven, disciplinary-grounded, integrative, and necessarily provisional understandings. For each aspect of interdisciplinary learning specific instructional principles can be derived. For example, a commitment to "purpose-driven" interdisciplinary learning suggests that rather than beginning a unit or project by teaching disciplinary parts, reserving synthesis for the end of an instructional design, learners may benefit from gaining a preliminary sense of the problem's space "whole," even if intuitive, and a clear sense of cognitive destination. Art and history instructors may begin with a deconstruction of an existing historical monument as a preview for the learners' own memorial design. How does this monument make you feel? What is the purpose of this monument? Similarly, in addressing sustainable cooperative practices, an instructor can request that students represent their initial intuitive theories to explain observable variations in the cooperative behavior of fishing communities. What else do we need to understand in order to explain observed differences in fishermen's behavior? In each case the form of integration—aesthetic synthesis or complex explanation—points in the direction of learning from the start.

A call for a disciplinary grounded understanding requires that instructors select or help select candidate disciplines or disciplinary insights to be introduced in an instructional design. What about the history of Vietnam can inform our monument creation? What artist tools do we have at our disposal to represent the past? What kinds of disciplinary misconceptions should we be attentive to? How can we weigh the relative contribution of constructs stemming across various fields to advance our target understanding? Here learners will benefit from opportunities to delve into particular disciplinary concepts and modes of thinking, able to advance the desired understandings. An iterative process of mutual calibration between disciplinary inputs and the developing integrative understanding can take place, one in which the very purposes of interdisciplinary learning can be adjusted as well.

At the heart of interdisciplinary learning, synthesis is shaped by the intellectual pursuit learners embark on. These range from complex explanations, to graphic designs, metaphors, and narratives embodying the purpose of learning initially established. Syntheses, small and substantial, must take place along the learning process and with an eye not merely to connecting fields but leveraging perspectives. Finally, attention to a critical stance vis-à-vis an evolving understanding calls for a critical eye that is able to challenge the emerging system of thought and understand our proclivity to err and the promise of deeper, broader, and meaningful learning.

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CHAPTER 20

COMPARING METHODS FOR CROSS-DISCIPLINARY RESEARCH

MICHAEL O'ROURKE

A survey of the methods of interdisciplinary and transdisciplinary research (hereafter, "cross-disciplinary research," or CDR) supports the suggestion that they are "fragmented," that is, distributed in unconnected ways across the intellectual landscape (Bammer 2013a). As cross-disciplinary responses to complex problems grow in number (van Noorden 2015), approaches, techniques, and tools multiply along with them. Cross-disciplinary research is highly contextual, with researchers developing sui generis strategies and methods that are sensitive to the exigencies of circumstance. These CDR responses combine many disciplines and professions, and so have no natural home; as a result, contributions to the published and gray literatures are widely dispersed, resulting in an unsurprising fragmentation of such efforts that yields "reinvention of the wheel" time and again (Bammer 2013b), and in some cases, reinvention of a square wheel.

Given the context-sensitivity of CDR, a multiplicity of methods is a virtue since it gives researchers more options from which to choose. However, when that multiplicity is widely dispersed and difficult to ascertain, it becomes difficult to locate the methods when you need them. The resulting inefficiency that fragmentation underwrites, then, motivates appreciation for the value of a systematic library of methods. Repositories (e.g., the National Cancer Institute's Team Science Toolkit–NCI 2015) and volumes (e.g., Bergmann et al. 2012) that systematize methods, tools, and approaches have appeared, reflecting careful consideration and comparison of methods used in cross-disciplinary activity. A comparative approach is valuable here, since it highlights similarities and differences that provide insight into what could be effective, while illuminating the features of a method that could prove problematic. This chapter contributes a comparative, philosophical perspective to the systematic organization of methods on offer to those engaged in CDR.

Research is only one mode of cross-disciplinary activity. Many education and training programs are cross-disciplinary, and practical, problem-solving contexts that do not involve a research component often exhibit cross-disciplinarity. Given limits of space, this chapter focuses on methods in CDR, although much of what is said applies mutatis mutandis to these other contexts. While the scope is limited in this way, the audience is still broad. Systematic

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organization has value for both cross-disciplinary practitioners and theorists, since it structures thinking about the range of variables that shape CDR, enhancing efficiency and prospects for project success.

With this broad audience in mind, the chapter begins with a brief historical review before analyzing and illustrating CDR methods. A comparative assessment of CDR methods is then presented that surveys a sample of prominent approaches to the organization of CDR methods before describing an alternate approach. The chapter closes with a discussion of outstanding challenges for those interested in comparing and organizing cross-disciplinary methods.

20.1 A Brief History

This chapter asks two questions: How should we think about methods for CDR? and How might they best be organized? Both questions are important, but my objectives here are modest: illuminate a few central characteristics of cross-disciplinary methods, discuss comparative perspectives on those methods, and present a specific comparative approach for organizing methods. I begin with a few historical reflections.

In general, setting a subject in a historical context is a helpful way of revealing its initial conditions and tracking the ebb and flow of interest and interpretation along the resulting arc of its development. Three historical contexts relevant to an investigation of CDR methods stand out. First, there is the history of reliance on methods in CDR, which can be interpreted as a history of CDR as a self-conscious research modality. As such, this is well documented in this volume and elsewhere (e.g., Klein 1990; Frodeman 2014). Such a history might limn the development of conceptual traditions underpinning systematic CDR, and this has also received attention (e.g., Fuller, this volume; Balsiger 2004).

Second, there is the history of the explicit discussion of methods for CDR. Explicit discussion of methods for CDR requires identification of CDR as a locus of methods, and this requires recognizing it as a stable research practice. Recognition of this sort often manifests as a form of practitioner self-consciousness that is aided by theoretical reflexivity. An important early contribution to community self-consciousness was the Organization of Economic Cooperation and Development meeting that yielded Apostel et al. (1972). This was followed by a few discussions of methods and methodology in the subsequent 20 years (e.g., Broido 1979; Birnbaum-More et al. 1990). Disciplinary methods in the context of interdisciplinary work are given at least as much attention as strictly interdisciplinary methods; when the latter are discussed, they are typically tied to integration in the context of interdisciplinary education (e.g., Newell 1990; Klein 1990).

As CDR has proliferated and matured over the past 25 years, explicit discussions of methods have proliferated, with NAS (2004) marking a watershed of CDR self-consciousness; others who have advanced the discussion of methods are McDonald et al. (2009), Repko (2012), Bergmann et al. (2012), Bammer (2013), and Cooke and Hilton (2015). These discussions include descriptions of methods appropriate to asking and investigating integrative questions, descriptions of methods for enhancing the practice of CDR, and as we will see in the final section of this chapter, critiques of the value of methods in CDR (e.g., Huutoniemi 2013; Frodeman 2014). Of particular interest are origin stories of CDR methods, which address the question of whether or not a method was "homegrown" in the context of CDR and designed to address a specific aspect of the CDR process (e.g., the Toolbox dialogue method, O'Rourke & Crowley 2013; TIPS, Wiek & Walter 2009; STIR, Fisher & Schuurbiers 2013). Homegrown methods of this sort were designed to function in the CDR context, and as such could have broader applicability across such contexts than imported methods.

Finally, there is the history of attempts to systematize methods in CDR. Attempts to organize CDR methods into useful and user-friendly taxonomies have grown in number and influence in recent years. Some of these use the comparative method—the method employed in this chapter—to organize methods by similarity and difference among features (e.g., Bergman et al. 2012; Bammer 2013). However, as these are relatively recent, a history of their development has yet to be written. This chapter, and especially sections 20.3 and 20.4, can be understood as a contribution to such a history.

20.2 Conceptual Foundations

Cross-disciplinary research methods are *research* methods, and understood in their most general form, research methods are *systematic, repeatable procedures for pursuing research objectives*; thus, CDR methods can be understood as systematic, repeatable procedures for pursuing CDR objectives. Conceiving methods as systematic and repeatable highlights the controlled, nonaccidental nature of methodical performance. Identifying conditions in which methods can be applied and wielding them successfully are skills that are typically hard won through meticulous practice. Conceiving of them as ways of pursuing objectives highlights their conformity to means/end logic; as Clough and Nutbrown (2002) insist, methods "*only* arise in the service of quite specific needs and purposes" (p. 27). Research ends are often restricted to data collection, coding, and analysis (e.g., Bellamy 2012), but since not all project aspects that can be addressed methodically are directly related to the data collected during the project, for example, identification of appropriate collaborators, I cast a wider net in this chapter.

A CDR method, then, supplies systematic means to pursue an end that is part of a CDR project, suggesting that how methods are individuated will correspond to how means are individuated relative to a specific end, and that can be done differently, at different scales, depending on the ends in view. This foregrounds the highly contextual nature of methods—they can be more or less systematic, more or less repeatable, more or less rigid, and more or less context dependent. Further, methods can be described at different levels of abstraction—they can be very specific and concrete (e.g., the Delphi technique conducted in a particular location for a particular problem), or more abstract and generic (e.g., dialogue methods). Thus, when one speaks of a method, one might be referring to a very specific procedure for solving a particular problem or a general family of procedures.

The contextual variability of method talk can be the source of confusion if certain differences are not respected. In speaking of methods, one can speak of research epistemologies to which they conform, such as empiricism or postpositivism, or research paradigms into which they figure, such as quantitative or qualitative research (Creswell 1994). However, it behooves one not to think of these higher-level organizational categories as methods. Similarly, it helps to distinguish concepts from methods—concepts are classificatory devices used to organize our experience, and while concepts will certainly figure into specification of methods, their primary role is to mark characteristics that differentiate methods.

Finally, it is important not to conflate methods with methodologies. Methodologies are abstract accounts that explain why specific methods work—they offer principled reasons to expect success when the specific methods they subsume are deployed in the right way in the right circumstances. Other terms used interchangeably with "method" are more innocuous, such as "tool" and "approach." "Tool" highlights the instrumental character of methods. "Approach," by contrast, is more generic, applying with equal legitimacy to methods and methodologies alike depending on the context. As long as its use does not suborn a slide from method to methodology, it can be used without loss of perspicuity.

20.3 Identifying Cross-Disciplinary Research Methods

No comprehensive census of CDR methods exists, even though there are impressive efforts at compiling methods in cross-disciplinary contexts, as discussed in the next section. The lack of a comprehensive census is due in part to considerations previously adduced, namely, the fragmentation of existing methods and the sui generis character of CDR questions. It is also due in part to the lack of a clear sense of what should count as specifically CDR methods. Multivariate statistical techniques are widely used in CDR projects, especially when those involve sociotechnical issues (Swanson et al. 2011), but should these techniques be included in a compendium of CDR methods? Cross-disciplinary research projects typically include experts with disciplinary training, and these experts will bring their disciplinary methods with them. In a novel CDR context, innovation could result in CDR variations on a disciplinary theme, but it is often the case that CDR embeds application of disciplinary techniques (Balsiger 2004; Repko 2012). There really is no right answer to the question of what should be regarded as CDR methods—disciplinary methods can be included under the CDR banner if desired, especially if they are of high value in cross-disciplinary contexts (e.g., philosophical analysis—see O'Rourke & Crowley 2013).

One way to begin thinking about CDR methods is to identify key characteristics of CDR that are supported by methodical performance. Three stand out as critical to much contemporary CDR:

1. *Integration*. A characteristic feature of CDR is the combination of social and epistemic elements and perspectives. While the foundational status of integration to CDR has been disputed (e.g., Holbrook 2013), many would agree with Klein (2012) who asserts that integration is a fundamental aspect of CDR. The need for integration is operative at all stages of the CDR process (Bergmann et al. 2012), creating problems for researchers that methods can help solve.
2. *Collaboration*. Cross-disciplinary work need not be collaborative, but it often is (Bergmann et al. 2012). From the other direction, collaborative research need not involve multiple disciplinary perspectives, but it often does (e.g., Stokols et al. 2008).

Thus, there is a substantial intersection between collaborative efforts and CDR efforts, generating the need to manage team process for CDR success.

3. *Communication*. Given the collaborative nature of much CDR, communication among collaborators is "at the heart of interdisciplinarity" (NAS 2004, p. 19) and will be critical to project success. Understood both relationally and transactionally, communication is key to ensuring coordination and learning (Hamalainen & Vahasantanen 2011), and methods representing many different perspectives can be brought to bear on communication problems in CDR (Klein 2013).

Each of these is a characteristic feature of all stages in the life cycle of a collaborative CDR project. Since methods also contribute to the life cycle of a CDR project, they will typically have implications for all three characteristics, as we will see below.

A common way to identify CDR methods is to examine stages of a typical CDR project and isolate methods that advance the project toward its objectives at that stage (e.g., Hall et al., this volume; Bergmann et al. 2012; Lang et al. 2012; Repko 2012). Stage models can be misleading, though, because they suggest that CDR projects are more linear than recursive, insistence to the contrary notwithstanding (Bergmann et al. 2012; Repko 2012). Rather than adding to these models, we can isolate CDR methods with the help of the process of decision-making, which is iterative and recursive at every stage in the life cycle of any CDR project and serves to advance the project toward its objectives (cf. Hall & O'Rourke 2014).

Simplifying this iterative, recursive decision process somewhat, it begins with identification of the question or problem that motivates the need for a decision, followed by an investigation into the responses to the question or problem that will be decision alternatives. This investigation can force one to loop back and do more work to clarify the problem before additional consideration results in a decision. Once the decision is made, it is typically evaluated, and here possible loops also exist if the decision is inadequate that take one back to reexamine the options or perhaps just select the runner-up alternative. If the decision is affirmed, the iterative process begins anew (see Figure 20.1).

These stages of decision-making can be used to frame the introduction of CDR methods, as illustrated in Table 20.1. Included in this table are examples that illustrate the variety of methods available to cross-disciplinary researchers and practitioners for pursuing research objectives. As noted above, each of these has implications for collaboration, integration, and communication; indeed, the ability of a method to enhance one of these characteristics can be regarded as a feature of the method. This ability is indicated in Table 20.1 with boldface type and a superscript "+" appended to the characteristic(s) enhanced by the method.

20.4 Comparing Cross-Disciplinary Research Methods

Informed selection of an appropriate method for a particular CDR task requires appreciation of the alternatives, and this depends on the ability to compare those alternatives along dimensions that (1) relevantly distinguish their strengths and weaknesses, and (2) align with project constraints and needs. A number of more or less comprehensive efforts to identify

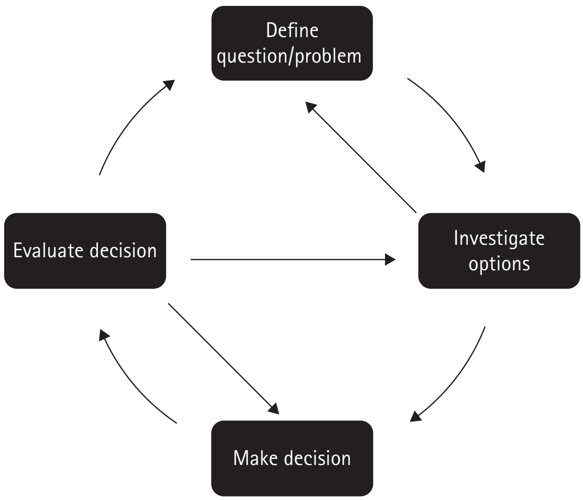

FIGURE 20.1 The iterative, recursive process of decision-making, which moves research forward at all stages in the life cycle of a CDR project.

these dimensions and use them to organize CDR methods have been conducted or are underway, including those reported in McDonald et al. (2009), Repko (2012), Bergmann et al. (2012), Bammer (2013), td-net (2015), and NCI (2015). After comparing these efforts in terms of the principles they use to organize CDR methods, this section considers in detail one specific way of developing a CDR methods repository.

Comparing taxonomies of methods is valuable because of what it reveals about the range of dimensions they use in systematizing the methods they consider. Anyone who seeks to organize the fragmented multiplicity of CDR methods must commit to an organizational schema constituted by a set of dimensions to compare and contrast methods that support CDR. The approach to comparing the taxonomies considered below analyzes them in terms of whether they are primarily *top-down* or *bottom-up*, that is, whether they impose an organizational structure on methods that is derived from theoretical considerations or whether they recover the structure from consideration of the methods themselves. In addition, *blueprints* are distinguished from *repositories*—the former outlines an organizational structure for CDR methods (among possibly other things) while the latter realizes one. By way of illustration, Table 20.1 supplies a top-down blueprint for methods classification.

An important effort is Repko (2012), a comprehensive introduction to the practice and theory of interdisciplinary research that can be interpreted as supplying a top-down blueprint for methods organization. This student textbook aims primarily at facilitating interdisciplinary research by individuals and does not highlight the collaborative contexts that have been especially important to the development of CDR methods. However, it supplies a framework that can be used to systematize methods in terms of the trajectory of a typical interdisciplinary research project. Referring to it as the "STEP" model, Repko's framework comprises 10 points of "decision or operation that one would normally take in almost any interdisciplinary research project" (p. 71). These include steps such as "define the problem or state the

Table 20.1 Illustrative CDR Methods Arranged According to Their Contribution to Decision-Making, with an Indication of the Characteristic(s) of the CDR Process They Enhance

Decision-Making Stages	Stage-Appropriate CDR Methods	Characteristic Enhanced
Identify Question/ Problem	• Increase inclusiveness of the research , e.g., opening communicative space (Wicks & Reason 2009)	• cl$^+$, cm, int
	• Gather information about the question/problem, e.g., citizen's jury (McDonald et al. 2009)	• cl, cm$^+$, int$^+$
	• Clarify research question/problem, e.g., Concept mapping (Heemskerk et al. 2003)	• cl, cm$^+$, int$^+$
Investigate Options	• Increase mutual understanding, e.g., Toolbox dialogue method (O'Rourke & Crowley 2013)	• cl$^+$, cm$^+$, int
	• Increase awareness of values on the team, e.g., value-focused thinking (Gregory et al. 2001)	• cl$^+$, cm$^+$, int
	• Combine research information and data, e.g., use of bio-ontologies (Leonelli 2008)	• cl, cm, int$^+$
Make Decision	• Via modeling, e.g., participatory modeling (Badham 2010)	• cl$^+$, cm, int$^+$
	• Via social techniques e.g., collaborative argument (Daniels & Walker 1996)	• cl$^+$, cm, int
	• Via integration of research information, e.g., multicriteria analysis (Huang et al. 2011)	• cl, cm, int$^+$
Evaluate Decision	• Evaluate the quality of an ongoing project, e.g., continuous formative evaluation (Lang et al. 2012)	• cl, cm, int
	• Evaluate the outcomes of that project, e.g., targeted assessment rubric (Boix Mansilla et al. 2010)	• cl, cm, int

research question," "conduct the literature search," and "create common ground between concepts and theories" (p. 74). Each step in this model is associated with methods designed to enable researchers to take it. Repko is careful to note the importance of disciplinary methods, which receive attention in the six steps that precede the integration phase in this model.

Overall, the goal of interdisciplinary research is integration, understood as "the cognitive process of critically evaluating disciplinary insights and creating common ground among them to create a more comprehensive understanding" (p. 263). Each of the four integrative steps in the interdisciplinary research process is associated with methods or "strategies" described at varying levels of abstraction, including four methods for integrating concepts (e.g., "the technique of redefinition"), a method for integrating theories, several strategies for "causal or propositional integration," and various ex-post tests for integrative outcomes. No effort is made to be comprehensive in identifying CDR methods—the methods are selected for their instrumental value in enabling a researcher to make the decisions associated with the step.

While Repko does not concern himself with a taxonomy of CDR methods, a second top-down approach presented in Bergmann et al. (2012) is explicitly interested in supplying a taxonomic blueprint for CDR methods. The "ISOE" model of transdisciplinary research, after the Institute for Social-Ecological Research in Frankfurt, recognizes the importance of societal practice and scientific practice, taking both to shape the three phases of transdisciplinary research: (1) constructing a common research problem, (2) conducting integrative research, and (3) bringing research results to fruition (p. 35). The focus in this work is on transdisciplinary research methods, and integrative methods in particular; pace Repko (2012), Bergmann and colleagues argue that integration is found at all phases of the transdisciplinary research process.

In addition to classifying CDR methods according to their appropriate research phases, they organize them analytically according to their integrative functions, such as "conceptual clarification and theoretical framing," "development and application of models," and "procedures and instruments of research organizations" (pp. 5–6). Crossing research phases with integrative functions yields a blueprint that combines systematic and common phase distinctions with functional distinctions that reflect a more idiosyncratic analysis. For example, shared research scenario models can help construct a common research problem (phase) by supporting the formulation of research questions and hypotheses (function).

Bammer (2013a) is also explicitly interested in supplying a blueprint for CDR methods, one that brings order to the fragmented multiplicity of methods, concepts, tools, case examples, and theories. While methods are not her sole focus, the blueprint she supplies is meant to accommodate them along with the others. The conceptual geography of the mode of research she calls "integrative applied research" is determined by asking five framing questions (For what and for whom? Which knowledge? How is the research undertaken? What is the context? What is the outcome?—pp. 20–21) about each of three domains ("Synthesizing disciplinary and stakeholder knowledge," "Understanding and managing diverse unknowns," and "Providing integrated research support for policy and practice change"—p. 15).

For each question, Bammer identifies categories of concepts and methods that she argues are key aspects of any response; for example, in response to the question, "Which knowledge?", Bammer identifies the following six categories: "systems view, scoping, boundary setting, framing, values, and harnessing and managing differences" (p. 30). Each of these categories focuses attention on specific types of concepts and methods that can be used to identify the knowledge relevant to understanding a domain, for example, scoping as a way of broadening concerns to include the "needs of the problem rather than the researchers' expertise" when dealing with research unknowns (p. 80). This complex taxonomy combines bottom-up appreciation for the interests and priorities of those engaged in CDR with certain top-down elements, such as the underappreciated domain of unknowns and the five framing questions. As such, it is somewhat unsystematic, but it still has a claim on comprehensive coverage of CDR.[1]

A distinctly bottom-up effort is the National Cancer Institute's Team Science Toolkit, an online repository that is user-generated and edited by a group of team science experts (NCI 2015). Intended to be an active home for the community of team science researchers, the Team Science Toolkit collects CDR methods in two "Resources" categories, measures and

[1] Bammer has also begun to develop a repository built to conform to this blueprint, organized multidimensionally according to resource type, domain, subject, and format, under the banner of "Integration and Implementation Sciences" (http://i2s.anu.edu.au).

tools. In addition to serving as a repository for measures and tools (133 tools and 41 measures as of this writing), the Toolkit comprises resource types that include an updated list of team science publications, a blog, funding opportunities, and job announcements. Its searchable database is organized in crosscutting fashion, with resource types crossed with a list of goals a researcher might be pursuing. The goals include the following: "learn about team science," "conduct effective team science," "enhance team performance," "provide institutional support," "train team members or students," "evaluate team science efforts," "engage community partners," and "collaborate virtually."

Since a cross-disciplinary researcher might be pursuing any one of these goals, the resolution supplied by this list helps increase the efficiency of the search. Additional resolution is provided in the form of an "editors' pick" designation that expresses the approval of a group of team science experts. Primarily a bibliographical resource, there is no analytically sophisticated, top-down blueprint that organizes the methods, and the methods that are included are not comparatively weighed as they are in Bergmann et al. (2012) and Bammer (2013a). As a repository of CDR methods designed to reflect available resources and be responsive to the needs of the community, though, the Team Science Toolkit serves as a hub that connects CDR practitioners to methods.[2]

As these efforts indicate, there is interest in surveying the range of CDR methods, systematically comparing them, and making them available for use by researchers and practitioners. This interest is motivated in part by the potential gains in efficiency to be made by the successful organization of CDR methods. The output of such an organizational effort can be used to build community, as the Team Science Toolkit demonstrates. Such a community would be home to both practitioners interested in the instrumental value of CDR methods for achieving their specific ends and theorists seeking to understand the intrinsic character of these methods and how they relate to the conduct and goals of CDR.

At this early stage in the systematization of CDR methods, it makes sense to be a pluralist and a contextualist, remaining open to approaches that vary according to interests and purposes. There is something to be said for stocking the shelves with a selection of organizational approaches so that the preferences of both theorists and practitioners can be assessed. The approaches above that meet in the middle through a combination of top-down and bottom-up elements, such as Bammer (2013a), are especially promising, as they allow for changes in the landscape of CDR to influence the way in which methods are organized.

Given the importance of the problems addressed by practitioners and the value that an organized compendium of methods could have for them, though, there is good reason to approach the problem of fragmentation in a way that focuses on their needs. Researchers engaged in a CDR project will do what they can to solve the problems they confront, often reacting to necessity with invention. Capturing these moments of innovation would be one way of staying abreast of current trends in CDR practice. The Team Science Toolkit is poised to capture these moments for team science, since it is constituted by contributions

[2] Another, smaller repository is maintained by the Network for Transdisciplinary Research (td-net). This site focuses on highlighting collaborative, cross-disciplinary methods that do not give "epistemic primacy to one particular thought style," and it also supplies links to similar repositories. Another feature of this site is its transparency, as it publishes its criteria for including and excluding the methods it lists. The criteria for inclusion are pragmatic: The method should be low tech, in ordinary language, aim at shared understanding or consensus, and facilitate exchanges between "thought styles."

from practitioners. Rather than filtering these through a layer of peer review, the Toolkit adopts a more grassroots approach that allows the community who uses the methods to determine its contents. What does not emerge, though, is an organizational structure for these methods. Presumably efficiency of access will be a value in designing such a structure, but other, perhaps surprising values might emerge as constraints on a bottom-up, grassroots compendium.

One bottom-up approach to organizing CDR methods that is well-suited to the task of reflecting the values of the CDR community could be called "Methods first!" This approach takes as its starting point the methods used by CDR practitioners and theorists, which can be identified via expert review (e.g., Bergmann et al. 2012) or crowdsourcing (e.g., NCI 2015). Once collected, they are examined for features that recommend them to potential users (e.g., emphasis on integration, collaboration, or communication, as indicated above) as well as features that complicate their use (e.g., requires substantial expertise). The features given prominence should align with values and priorities of users, which will vary and could be identified using a wiki approach that captures input on the fly. Each of these features can be understood as a dimension along which methods vary, and the compiled set of them serves as a multidimensional checklist for comparing CDR methods.[3]

McDonald et al. (2009) is a good example of this approach. They supply an annotated catalog of dialogue methods that are analyzed in terms of the following pragmatic features of interest to practitioners: number of participants, process characteristics, "locus of control" (i.e., whether organizers or participants are in control of the method during its employment), "degree of structure," whether preparatory work is required, strengths, and limitations (p. 12). A good start, this list could be augmented with additional pragmatic features, such as cost (money or time), whether expertise is required, whether expert participants are required, and evidence of effectiveness. Theoretical features are also possible, such as how a method relates to the CDR process and what philosophical commitments it makes. There is no real limit to the number of features that could be used here. One important virtue of this bottom-up, feature-based approach would be that it could support comparative evaluation and weighing of the strengths and weaknesses of each method for particular contexts.

Several reasons favor a "Methods first!" approach. First, no matter how thoughtful a group of experts will be, they will not be able to anticipate all of the relevant ways in which CDR projects might be aided by methodical performance. Hence, a top-down structure for methods organization will be unduly restrictive and may also be conservative in a way that hinders CDR responses. One way to avoid being overly restrictive is to have the principal organizational categories be very general, but this simply transfers responsibility for determining structural distinctions to the users of the resource, so why not just build that in from the start? Second, the argument for a wiki-based approach to methods organization meets several desiderata for systematic response to the fragmentation of CDR methods:

1. Respect the sui generis character of CDR questions.
2. Allow for bottom-up investment in the resource.
3. Allow for dynamic adjustment of structure to make the resource more flexible and responsive to changes in CDR practice.

[3] Here we take a cue from the comparative method in linguistics. See, for example, Trask (1996).

Giving CDR practitioners and theorists control of the resource will ensure that innovations and contemporary currents are reflected, making it more valuable for those with a stake in CDR. Third, substantial participation by the CDR community would enable a broader and more nimble comparative evaluation of existing methods. This has two important benefits: first, it enables the community to track the use of CDR methods, and for that matter, the resource itself; second, comparative evaluation of the performance of methods in specific contexts will induce even greater efficiency into the resource, making it easier for researchers to choose wisely among the methods that are available to them.

20.5 Against Method: Contemporary Debates and Future Directions

No attempt to organize is innocent. Organization reflects assumptions about the domain—in this case, the process of CDR—and it requires contingent and potentially objectionable decisions that foreground certain aspects of the domain and background others. Two decisions behind the account so far are that (1) CDR methods can be compared and systematically related, and (2) it is worthwhile to organize them so as to make them readily available to future practitioners. These decisions can be challenged. For example, methods can be characterized as stable and rigid, reflecting the mature "normal science" of an established discipline; so understood, they would appear to lack the flexibility necessary to serve CDR goals, which are context sensitive and often unprecedented. Echoing Feyerabend's comment on scientific method, we might say that "the idea of a fixed method . . . arises from too naïve a view of man and his social surroundings" (1970, p. 25).

Some of what Huutoniemi (2014) argues can be interpreted this way. She criticizes "methodological foundationalism," according to which methods underwrite "uniformity and predictability," ensuring rigor and professionalism in the pursuit of scientific goals (pp. 10–11). "Methods," she argues, "rationalize behavior only in epistemic cultures where they are institutions," and the "methodical aspects of research" should be set aside when dealing with the complex problems addressed by CDR in favor of "ecological or situational aspects" (p. 10). Methods can become "heuristic devices," Huutoniemi acknowledges, if wielded sensitively in CDR contexts; further, the "virtuosity, personal knowledge and creative skills" that are prized in these contexts can be on display when one modifies a previously developed method to work effectively in a new context.

A similar criticism of the decisions behind the discussion in previous sections is found in Frodeman (2014). Frodeman argues that "the hard headedness of method" consists in a kind of "proceduralism" that "assumes that one standard is fairly applicable to all" (p. 49). Methodism, as he refers to it, "allows us to bracket discussion of purposes and goals and give the patina of objectivity to the outcome" (p. 49). This perspective motivates his critique of the interdisciplinary research steps of the sort found in Repko (2012) and Bammer (2013a). He criticizes Repko's view as developing a version of methodism that comes as close to rigid proceduralism as any considered above, and imposing constraints that limit its applicability in collaborative, expert CDR. Bammer is cited less for her map of the space than for her commitment to a "Big Science" project that could result in the development of a discipline of interdisciplinarity that comes with its own limiting methodology. Frodeman's alternative to methodism celebrates "bricolage," "reconnaissance," and the priority of character over methodology (p. 46). Siding with Krohn (this volume), he is skeptical of the claim that CDR has any generalizable methodology.

Frodeman and Huutoniemi reject unreflective commitment to rigid CDR methods, especially at this early stage in their development. Blind allegiance to methods without sensitivity to the research context is in general a bad plan for CDR practitioners; however, there is nothing about the drive to systematize the plethora of CDR methods that requires it. Indeed, Frodeman acknowledges the value of transferable skill sets and the "sharing of a wealth of particular insights and rules of thumb that have developed in a piecemeal manner" (p. 45). For her part, Huutoniemi recognizes that methods can be remade as heuristic devices, suggesting that it is not so much the methods that are rigid as the people who employ them. If anything, the flexibility and responsiveness to practice urged in the previous sections is implied by their critiques.

A related criticism of the drive to organize CDR methods pertains to the role such a project could play in efforts to "discipline interdisciplinarity" (e.g., Bammer 2013a, 2013b). Although the highly contextual nature of CDR could motivate one to regard the multiplicity of methods as a signal of the vigor of this mode of research, others see it as a problem to be solved. Bammer (2013b), for example, sees this multiplicity as fragmentation and argues that the best way to induce efficiency and knowledge sharing is by creating a new discipline that contains the "extensive array of concepts, methods, and case studies that interdisciplinary research, education, and communication have produced and continue to provide" (p. 404). But this sort of "disciplinary capture" (Briggle & Frodeman 2016) could lead these researchers to turn inward, communicating with one another in ways that are more academic (e.g., 300-page tomes) and less accessible to those outside of their new discipline who have serious problems to address. If the search for community led CDR practitioners to lose their contextual flexibility, that would mean replacing inefficiency with insensitivity. This prospect is cause for concern, but the transition from a vibrant, heterogeneous community to an isolated echo chamber is not inevitable. Those who wish to create a community to enhance efficiency, in part by systematizing methods, would need to remain mindful of their role as disciplinary boundary crossers and integrators.[4]

This chapter has argued that there is value in organizing CDR methods. Thinking systematically about process should pay dividends in terms of efficiency and effectiveness, and the opportunity to engage with context in a way informed by previous methodical successes should spur innovation and creativity. In closing, I highlight three areas that require attention as this effort goes forward. First, systematic treatment of methods will invariably highlight their epistemic character, related as it is to their role in the research process, but it should also acknowledge their ethical side. Because they often seem endorsed by the research community, methods can undermine the ability of researchers to identify the range of biases that undermine the quality of research, including experimenter bias, confirmation bias, and implicit bias. Attention to sources of bias is especially important in the context of

[4] Examples of similar communities including modeling (e.g., Schmitt Olabisi et al. 2013) and statistics (e.g., Smithson 2013).

CDR, given its problem-focused and policy-relevant character and its direct impact on the lives and situations of nonresearchers.

Second, to the extent possible a compendium of methods should attend to failures as much as successes. McDonald et al. (2009) discuss the limitations of the dialogue methods they consider, and this is a step in the right direction—consistent with Huutoniemi's observation noted above, methods are tied to epistemic cultures that supply the methodologies that explain them and justify their application, and for this reason they will not always work. But further, it would be useful to note "good ideas" that came to nought, as "square wheels" such as these can be as instructive to the practitioner as fully functional wheels. Finally, it is important that any effort to organize methods be supplemented by efforts to evaluate them. Given the highly contextual nature of CDR, information about auspicious application conditions can help a practitioner decide among otherwise equally attractive approaches.

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CHAPTER 21

SYSTEMS THINKING

SYTSE STRIJBOS

Systems thinking is an innovation-oriented movement with a broad program rather than a sharply delineated field or discipline. It arose in the middle of the twentieth century, inter alia, in biology, economy, engineering, and management sciences, related to a variety of postwar developments, such as cybernetics, information theory, game and decision theory, automaton theory, systems engineering, and operations research. According to the founders of the movement, all these developments concur inasmuch as, in one way or another, they relate to a basic reorientation in scientific thinking attempting to overcome ever-increasing specialization, and trying to shift from reductionist to holistic thinking, while acknowledging the unity of reality and the interconnections between its different parts and aspects. The systems program is ultimately based on the conviction that it embodies a major step in the history of science aiming to transcend the Cartesian program in the conduct of science and the study of the world as an assemblage of parts that can be broken apart and analyzed separately. This step should even result into a new scientific worldview that replaces the domination of a mechanistic or technical world picture (Strijbos 1988).

By pursuing such an ambitious program, systems thinking represents an important form that interdisciplinarity has adopted since World War II. There have been a number of attempts to define interdisciplinarity and identify its different types. Of particular interest in the present case is Margaret Boden (1999), who distinguishes six forms ranging from weak to strong: encyclopedic, contextualizing, sharing, cooperative, generalizing, and integrative types of interdisciplinarity. Encyclopedic interdisciplinarity requires no exchange or sharing between any disciplines involved, whereas integrative interdisciplinarity demands rigorous interaction. The latter is thus, according to Boden, the most genuine kind of interdisciplinarity as "an enterprise in which some of the concepts and insights of one discipline contribute to the problems and theories of another—preferably in both directions."

How does systems thinking fit into this typology? Boden labels the proposal for a "general systems theory" that was launched by Ludwig von Bertalanffy (1901–1972) and others in the middle of the twentieth century and Norbert Wiener's closely related idea of cybernetics as examples of "generalizing interdisciplinarity," defined as "an enterprise in which a single theoretical perspective is applied to a wide range of previously distinct disciplines." Also the more recent developments in the area of complexity studies can be regarded as an example of this type. Boden (1999, p. 20) correctly notes that it is no accident that these examples are

Strijbos, S., *Systems Thinking.* In: *The Oxford Handbook of Interdisciplinarity, Second Edition.* Edited by Robert Frodeman, Julie Thompson Klein, and Roberto C. S. Pacheco: Oxford University Press (2017). © Oxford University Press. DOI 10.1093/oxfordhb/9780198733522.013.24

all heavily mathematical: "The abstractness of mathematics enables it to be applied, in principle, to all other disciplines."

When Boden refers to von Bertalanffy's proposal for a "general system theory," she nevertheless fails to note some of the ways the systems program has developed and its underlying fundamental thrust. In his later work, von Bertalanffy for instance has distinguished between general system theory in a broader sense and in a narrower sense. Although von Bertalanffy's own theoretical work focuses on the latter, he stresses in his *General System Theory: Foundations, Developments, Applications* (1968), a collection of articles published over a period of more than 20 years, that he had both in mind from the outset. The main objective of the systems program is thus not just the search for a certain unifying theory—general system theory in a narrower sense—but, what is more, the breakthrough of a new paradigm in science—general system theory in a broader sense. To promote this broad program, von Bertalanffy joined with Boulding, Rapoport, and Gerard to establish in 1954 the Society for General Systems Research, an association that still exists under the name of the International Society for the Systems Sciences. Stimulated by this new scientific association, a dynamic, broad-based endeavor has developed and a multiplicity of approaches and trends has arisen.

With the increasing expansion of systems thinking, von Bertalanffy felt the need to distinguish different domains. Following his distinctions, the wide range of studies in the systems program can be divided into three basic types. The first is *systems science*, which can be defined as the scientific exploration and theory of "systems" in the various sciences, such as biology, sociology, economics, and so forth, while general system theory concerns the principles that apply to all. The second realm is *systems approach in technology and management*, which concerns problems arising in modern technology and society. While philosophy is present in the areas of systems science and systems technology, *systems philosophy* can be distinguished as a third domain in its own right. In the view of leading systems thinkers such as von Bertalanffy, the introduction of "system" as a key concept entails a total reorientation not only in science and technology but also in philosophical thought.

To explore the implications of systems thinking for interdisciplinarity it is appropriate to consider each of the domains in more detail. In what follows some main lines are sketched of the systems field, rather than pursuing an encyclopedic overview or a critical study and evaluation.

21.1 Systems Science

The well-known stock phrase "A whole is more than the sum of its parts" stems from a tradition in Greek philosophy, older than the conceptual use of the term "system," that speaks of wholes that are composed of parts. This whole–part relationship attracted renewed scientific interest in wholeness arising in the early twentieth century. Exploring the genealogy of contemporary systems thinking, reference can be made to Jan C. Smuts (1870–1950) and Alexander A. Bogdanov (1873–1928). Both anticipated systems ideas at the beginning of the twentieth century. However, the conceptual use of "system" as a technical term in science and technology arose some decades later and has become ubiquitous since the 1950s.

The philosopher–biologist von Bertalanffy became one of the leading figures in the rise of systems thinking by coining the concept of a "system," or more precisely the concept of an "open system," as a key concept in the quest for a unified science incorporating all the disciplines, each corresponding to a certain segment of the empirical world. Just like Smuts, von Bertalanffy was also inspired by the debate in the biological sciences in the first decades of the twentieth century. Struggling with the controversy between two competing views, the dominant mechanistic-causal approach and vitalist-teleological conception, he did not take one or the other side but proposed what he called an "organismic" view. At issue was the possibility of an explanation for the phenomena of life that would have the status of an exact science, not through a *reduction* of biology to physics but through the *expansion* of classical physics into a broader, exact natural science. Von Bertalanffy considered this idea of expansion of scientific concepts as a key that opens the door to very far-reaching scientific developments. The extension of the domain of exact science from physics to biology must be carried further. Organismic biology, he argued, which focuses on the study of the organism as an open system (in contrast to the study of closed systems in classical physics) becomes in its turn a borderline case of the so-called general system theory. The concept of the "open system" was for him the truly "general system" concept enabling the integration of all the sciences into a general system theory.

Like von Bertalanffy, the economist Kenneth E. Boulding (1910–1995) was one of the early pioneers and founders of the systems movement. Being aware of the increasing difficulty of profitable exchange among the disciplines the more science breaks into subgroups, Boulding started pursuing the unity of sciences as an economist within the social sciences. Early in his scientific career he became convinced that all the social sciences were fundamentally studying the same thing, which is the social system. In his book *The Image: Knowledge in Life and Society* (1956), Boulding introduced the "image" concept, apparently inspired by Shannon and Weaver's concept of information, serving as a basis for the desired integration of the social sciences. And in a classic article "General Systems Theory: The Skeleton of Science," published in the same year, he pointed out the next step toward a general systems theory, incorporating all the sciences.

Boulding sketched two possible approaches in the interdisciplinary quest for a general systems theory. A first approach is to identify general phenomena that are found in many disciplines, such as the phenomenon of growth. A second, more systematic, approach is to arrange the empirical fields in a certain hierarchic order, a hierarchy of systems in which each higher systems level has a higher degree of complexity. This issue of hierarchy has subsequently been widely discussed in the systems literature, for example, by Herbert Simon in an often reprinted paper, "The Architecture of Complexity: Hierarchic Systems," originally published in 1962.

Looking back over a period of more than 40 years, Peter Checkland (1999, p. 49) made the observation that the original interdisciplinary project of the founders cannot be declared a success. A meta-level kind of approach leading to a greater unification of the sciences as envisaged has not occurred. However, one can admit that systems ideas and concepts have been incorporated in many disciplines. And sometimes new systems concepts and insights born in one discipline have contributed to the problems and theories of another. An impressive example of such an exchange between disciplines—or integrative interdisciplinarity, speaking in Boden's typology—is the work of the social scientist Niklas Luhmann (1927–1998).

Aiming for a unified social theory, a general theory of social systems, Luhmann argues in his *Social Systems* (1995) that two subsequent paradigm changes have taken place on the level of general systems theory, showing a shift from an ontological to a more functionalistic systems concept, that is, from thinking in terms of wholes as unchangeable substances to systems that maintains themselves in a dynamic exchange with their environment. The first move in this direction was due to von Bertalanffy in the mid-1950s. After he proposed the concept of the "open system" a transformation of thinking took place in which the traditional difference between *whole and part* was replaced by *system and environment*. Like any paradigm change, Luhmann notes, this implies a conceptual broadening. What has been conceived of previously as the difference between whole and part, the old paradigm, was reformulated by this new schema as system differentiation and thereby built into the new paradigm. Systems differentiation can be understood as the repetition within systems of the difference between system and environment.

The second paradigm change and move toward a more radical functionalistic way of thinking is due to developments in systems science leading to a theory of *self-referential systems*. Initial efforts in the 1960s, in which Heinz von Foerster (1911–2002) played a leading role, employed the concept of self-organization. Self-organization is the phenomenon of self-reference with regard to the structure of a system, that is to say that structural changes are produced by the system itself. Self-reference in a more encompassing way, however, also include the elements composing a system. For this purpose the biologists Humberto Maturana and Francisco Varela (1946–2001) created the term *autopoiesis* (self-creation). Autopoiesis thus means that a system has the ability to reproduce itself at the level of its own elements.

According to Luhmann, a theory of self-referential systems as the most recent general system theory opened up important avenues for a general theory of social systems. This broadening of the general system concept from "open system" to "self-referential system" enabled Luhmann to avoid criticisms of the views of Talcott Parsons, his great predecessor in sociology, whose social systems theory was the dominant paradigm in sociology during the 1950s and 1960s. While very influential for a few decades, Parsons's systems theory was also widely criticized as a legitimization of the status quo. It was charged that Parsons's systems approach was inherently conservative in its focus on the maintenance of social order and in emphasizing consensus at the expense of acknowledging social change and conflict. Profiting from newer developments in systems science, Luhmann in the 1980s proposed a new social systems theory, turning around Parsons's structural-functionalism into a functional-structural systems approach.

21.2 Systems Approach in Technology and Management

The roots of this domain in systems thinking are quite complex and go back to various developments that happened during or shortly after World War II. One important aspect is that engineering has been led to think not in terms of single machines and separate technical artifacts but in terms of larger "systems": the engineering of the telephone network, for example, rather than the telephone instrument or the switching equipment. Traditionally, engineers are used to tackling practical problems by analyzing their parts and finding a solution for the different parts. As the name *systems engineering* suggests, the idea took hold that the traditional approach of engineering separate components needed to be extended to approach systems made up out of many components that are interacting. Engineers speak about electric systems, power systems, transportation systems, computer systems, and so forth. The initial use of the term "systems engineering" with roughly its present meaning probably began in the early 1940s at the Bell Telephone Laboratories. A leading pioneer was the electrical engineer Arthur D. Hall (1925–2006), who worked for many years at Bell Labs and in 1962 published the first significant book on systems engineering, *A Methodology for Systems Engineering*.

A development closely related to systems engineering is *operations research* or "operational research" as it is known in the United Kingdom. Briefly discussing the difference between both fields, Hall (1962, p. 18) noted that operations research is usually concerned with the operation and the optimization of an existing system, including both humans and machines, while in contrast, systems engineering focuses on the planning and design of new systems to better perform existing operations or to implement new ones never performed before. In the aftermath of the war, C. West Churchman (1913–2004) and his first doctoral student, Russell L. Ackoff (1919–2009), who were inspired by American pragmatism and aimed to apply this philosophy to societal issues, became leading scholars in North America in the incipient fields of operations research and systems thinking. Together with Ackoff and Arnoff, Churchman published in 1957 one of the field's first textbooks, *Introduction to Operations Research*, which became internationally recognized. The book emphasized an interdisciplinary team-based approach, characterizing operations research as "the application of scientific methods, techniques and tools to problems involving the operations of a system so as to provide those in control of the system with the optimum solution to the problem."

Simultaneously with the development of systems engineering and operations research, an approach emerged in the 1950s that was known as *systems analysis*; at that time it was closely associated with the RAND Corporation (RAND being an acronym for "Research ANd Development"), a not-for-profit organization in the advice-giving business established in 1948. From the 1960s, RAND-style systems analysis began to find broader industrial and governmental uses, leading to a 1972 initiative by 12 nations to set up a nongovernmental interdisciplinary research institute in Austria—the International Institute for Applied Systems Analysis (IIASA). Systems analysis can be defined as "analysis to suggest a course of action by systematically examining the costs, effectiveness and risks of alternative policies and strategies—and designing additional ones if those examined are found wanting." A case described by Miser and Quade (1985) is a policy analysis clarifying the issues for a governmental decision in the Netherlands after the North Sea flood of 1953 about the protection of the Oosterschelde estuary from flooding.

Acknowledging the differences that are present in their background and concerning particular features of systems engineering, systems analysis, and operations research, these systems approaches show important commonalities. They all rely heavily on the methods of the natural and technical sciences. Consequently they aspire to describe phenomena by mathematical-statistical models, while holding the assumption that an optimal solution exists for a problem situation and may be uncovered in this way. Another aspect of this family of approaches is *systems dynamics*, which gained a certain reputation in the 1970s and appeared on the radar of a worldwide forum due to an alarming report by Meadows et al. (1972) for the Club of Rome, *The Limits to Growth*, a study on world modeling and global sustainability.

Examining the origins and nature of systems engineering and systems analysis, Checkland (1978, p. 107) concluded that a single view underlies these approaches: "There is a desired state, S(1), and a present state S(0), and alternative ways of getting from S(0) to S(1)." "Problem solving," according to this view, consists of "defining S(1) and S(0) and selecting the best means of reducing the difference between them." This constitutes what Checkland called *"hard" systems thinking*, defined as any kind of systems thinking that adopts the means–end schema. Although this model may be useful for engineering-type problems, it has a very limited applicability. Hard systems thinking demands that objectives can be clearly defined; however, an important aspect of many "soft" problem situations is that the involved parties are likely to see the problem situation differently and define objectives accordingly. Checkland was thus faced with the challenge of rethinking the failing concept of a systems approach rooted in the engineering tradition. This led to his conceptualization of a soft systems approach in the 1970s that admits the human dimension, dealing with multiple perceptions of reality, values, and interests of the people involved.

The later work of Churchman and Ackoff in North America is similar to the scientific program started in the 1970s by Peter B. Checkland and his colleagues at Lancaster University in the UK. Dissatisfied or even disillusioned with the course of operations research, Ackoff argued that mainstream operations research as it had developed since 1950 was only useful in dealing with problem areas that can be decomposed into problems that are independent of each other. However, major societal problems such as discrimination, inequality within and between nations, increasing criminality, and so on, must be attacked holistically, with a comprehensive systems approach. Ackoff's dispute with the operations research community culminated in two papers (Ackoff 1979a, 1979b) in which he called for a new paradigm breaking away from the ever-increasing "mathematization" of operations research and for a return to true interdisciplinarity, involving in the research of all those affected by it.

In their plea for a systems approach, Ackoff and Churchman not only triggered debate in the operations research community about the nature and characteristics of the field but also delivered a fresh input to the debate in the systems movement on interdisciplinarity. In 1963 Ackoff published an article in the *Yearbook of the Society for General Systems Research* in which he argued for a new vision of an integrating systems science and the difference between the conception of general systems theory. According to Ackoff, the conception of a general system theory endeavors to achieve integration using the results that are available in the monodisciplines, that is to say it attempts a unity *afterward*. However, in his view "the integral" precedes the disciplinary splitting of a problem into disjoint chunks—"Therefore, posing the problem of unifying science by interrelating disciplinary output either in the forms of facts or concepts (i.e. logical positivism), or laws or theories (i.e. general system theory), is to try to lock the barn door after the horse has gone" (Ackoff 1963, p. 120).

Ackoff's idea that integration has to take place a priori, that is, in the phase of knowledge production, implies that he put emphasis on science as an activity and the scientific method employed in that activity. Integral knowledge requires an integration of the disciplines involved within an interdisciplinary framework. The integration must come during, not after, the performance of the research. In his conception of systems science and systems research, Ackoff is on sounder ground than von Bertalanffy's general systems theory because it takes systems as it finds them, in all their multidisciplinary glory.

21.3 Systems Philosophy

The worlds of science, technology, and philosophy do not exist in isolation from each other. Because philosophy raises questions that are fundamental for science and technology, one could argue that philosophy is by nature an interdisciplinary endeavor. For the sake of clarity, it is therefore useful to distinguish some of the various meanings in which the term "systems philosophy" can be used, each standing for different themes and a different role of philosophy in the systems field.

First, systems philosophy deals with the fundamental philosophical issues involved in the realm of systems science. Such a fundamental issue in biology is the question "What is life?" or "How do we understand the phenomena of life?" As discussed, von Bertalanffy advocated a so-called organismic conception—the view that the organism is a whole or system, transcending its parts when these are considered in isolation. Searching for a satisfying understanding of the Aristotelian dictum of the whole that is more than its parts, von Bertalanffy at the same time took a stand on another fundamental problem of Greek philosophy. There is the famous statement of Heraclitus: "Panta rhei," everything is in flux, arguing against Parmenides, who taught that only static being was real and that change is an illusion. In this controversy, which has persisted in one form or another across the whole of Western philosophy and science, systems science adopts the Heraclitean point of view. The model of the organism as an open system implies that life has to be understood as primarily a stream of life. Forms and structures that manifest themselves in living nature are in von Bertalanffy's view secondary, just like social structures are secondary in Luhmann's understanding of social phenomena. Systems science thus manifests a totally dynamic view of reality in which enduring structures seem to evaporate and become volatile and dynamic.

Second, systems philosophy concerns the philosophical foundations of the systems approach in technology and management. Comparing Ackoff with von Bertalanffy, one notices that they agree that society is going through an important intellectual revolution that will usher us into a new era of science and society—in Ackoff's wording, going from a machine age to a systems age. One of the important characteristics of systems science, as we have seen above, is the priority given to the dynamic and flowing character of reality. The same characteristic seems to hold for systems research when Ackoff (1981, p. 16) points out that there is a turn from analysis to synthesis, which implies a turn to a functional understanding of the thing to be explained in terms of its role or function within its containing whole or environment. The synthetic approach does not exclude analysis, but in the systems age synthesis has priority over analysis, and function over structure. The turn from the machine age to the systems age even implies a different understanding of reality. Characteristic of the machine age is the deistic view in which God is regarded as the creator of the world as a machine that runs according to fixed laws. While the machine age and deism personify God as the Creator God, who is independent from his handiwork, God loses this personal and independent character in the systems age. Like Smuts's holism, Ackoff's (1981,

p. 19) systems thinking is also infused with a rationalist pantheistic view in which the world coincides with God as the largest, all-embracing whole.

In a more elaborate way this is also the case in Churchman's work. In his view, the most fundamental and serious issues of the systems approach concern the problem of improvement. If we assume that we have the capability to improve systems, then what exactly do we mean by "improvement" in designing interventions for our social systems? Churchman (1968, p. 2) concisely describes the fundamental problem right at the start of his book *Challenge to Reason*: "How can we design improvement in large systems without understanding the whole system, and if the answer is that we cannot, how is it possible to understand the whole system?" In a line of reasoning similar to Ackoff's, Churchman points to the tradition of analysis in Western thought that presumes that parts of the whole system can be studied and improved more or less in isolation from the rest of the system. And comparable to Ackoff, Churchman also discerns two differing views of the whole system and its relationship to God. If we assume that a supreme being exists, Churchman (1979, p. 41, italics added) says, "then we have the conceptual problem of describing (modeling) His relationship to the rest of reality." He continues: "Two plausible hypotheses come to mind. The Augustinian hypothesis (in systems language) is that *God is the designer* of the real system, as well as its decision maker. . . . The other hypothesis, the one chosen by Spinoza, is to say that *God* **is** the whole system: He is the most general system."

Third, there is the aspiration to formulate a systems philosophy as a new philosophy, of which Archie Bahm, Mario Bunge, and Ervin Laszlo are the chief proponents. As a prolific author of many books, Laszlo became probably the most influential, also outside the academic community. Building on von Bertalanffy's ideas for a new scientific worldview he developed in the 1970s, the framework for a systems philosophy in tune with the latest developments in science and technology. This represents a total reorientation of thought, aiming to overthrow and replace the dominating mechanistic worldview and its incarnation in the industrialized and commercialized society of today. The dynamic view of reality that, as we noticed, underlies von Bertalanffy's and Luhmann's theoretical ideas and concepts, is a typical feature of the systems view of the world that has been summarized by Laszlo (1972, pp. 80–81) as follows: "Imagine a universe made up not of things in space and time, but of patterned flows extending throughout its reaches. . . . Some of the flows tie themselves into knots and twist into a relatively stable pattern. Now there is something there—something enduring . . . 'Things' are emerging from the background of flows like knots tied on a fishing net."

Laszlo's philosophical conceptions culminate in his view on the future of humankind in our globalizing world. The general thrust of the many books that he published over a period of more than 40 years is that contemporary society is in a critical stage of development. World society can get out of the danger zone if there is a complete turnabout at the immaterial-spiritual level. In Laszlo's view, there is not only the need to bridge the gap between the sciences, gaining an integral scientific view of the world—more important even is the integrating role of systems thinking in bridging the divide between science and religion, between science and spirituality. The interdisciplinary challenge for systems thinking is thus extended in Laszlo's view to the search for a new uniting spirituality for humankind. Based on an evolutionary dynamic view of the universe, he argues that there exists an interconnecting cosmic field, the Akashic field that conserves and conveys information, a subtle sea of fluctuating energies from which all things arise (Laszlo 2004). Similar to the pantheism of Churchman and Ackoff, Laszlo also thus rejects a personal God who is separated as creator from the universe. In his systems view of the universe, God is the all-embracing cosmic consciousness, and we are part of that.

21.4 Subsequent Developments

Although *systems science* is perpetuated in newer developments in special areas such as systems biology, chaos theory, and the study of complex systems (for instance at the Santa Fe Institute, New Mexico, United States), the original interdisciplinary program of the founders of the systems movement for a general system theory has largely failed in its early aspirations to create a greater unification of the sciences, setting out general laws and principles governing the behavior of any type of system. On the contrary, the systems movement was more successful in creating interdisciplinary *approaches in technology and management* for tackling practical real-world problems. Jackson (2001, p. 234) offers two reasons why systems approaches in this domain should have proven so successful. First, practical problems are by nature interdisciplinary and do not correspond to a single monodiscipline. Second, the systems idea provides a useful antidote to reductionism and enshrines a commitment to looking at real-world problems in terms of wholes and interconnected elements. As a third reason I would like to add the influence in this domain of other schools of thought from continental philosophy. With the work of Ackoff and Churchman in North America and that of Checkland in the UK, this domain has not come to a standstill. Moving from "hard systems thinking" to "soft systems thinking," these authors have in principle opened the way to further debates and advances. Ideas that have inspired subsequent developments derive from social theory, philosophy, and theology. The account I give here is necessarily biased by my own role played in programmatic research efforts.

In the 1980s a program entered the stage that has been called "critical systems thinking," a program that involved many people and gained a strong basis at the University of Hull in the UK with the appointment of Michael C. Jackson in 1979 (Jackson is also the editor-in-chief of a central journal in the systems community, *Systems Research and Behavioral Science*). An important source that supplies information about the broader context of critical systems thinking is a collection of articles, *Critical Systems Thinking* (1991), edited by two of its main proponents, Robert L. Flood and Michael C. Jackson.

Inspired by the social theorist and philosopher Jürgen Habermas, critical systems thinking tried to overcome shortcomings in soft systems thinking. Similar to Checkland's critical analysis of the origins and nature of hard systems thinking in 1978, Jackson embarked on a similar critique of the ambitions of soft systems thinking in an early article published in 1982 on the nature of soft systems thinking. He arrives at the conclusion that although soft systems thinking has attacked the technical rationality embodied in hard systems thinking, one crucial element was never targeted—it still proceeds from existing power relationships. In Jackson's own words, "Soft systems thinking is most suitable for the kind of social engineering that ensures the continued survival, by adaptation, of existing social elites. It is not authoritarian like systems analysis or systems engineering, but it is conservative-reformist" (Jackson 1982, p. 28).

Independently of the group at Hull University, an important contribution to the strand of critical systems thinking was made in the 1980s by Werner Ulrich from the University of Fribourg in Switzerland. As a student of Churchman, and inspired by Kant's critical philosophy and Habermas's critical social theory, Ulrich (1994) launched a program that led to the conception of "critical systems heuristics." A distinguishing feature of this dialect of critical systems thinking is its methodological core principle, known as "boundary critique." While the two strands of critical systems thinking were developed independently, Ulrich has analyzed important differences in a 2003 article, followed by a brief response from Jackson and answer from Ulrich.

A fruitful encounter between systems thinking and another continental philosophical tradition also appeared in a program that emerged in the late 1990s. Inspired by the legacy of the philosopher Herman Dooyeweerd (1894–1977) and that of his student Hendrik van Riessen (1911–2000) from the VU University in Amsterdam, an international group of scholars affiliated with universities in different countries engaged in interdisciplinary cooperation. This group takes a critical stance against the dominant Western idea of an autonomous human rationality and the absolute dominance of a scientific view of the world as the final horizon for human understanding. In this connection, it attempts to break with deism and a mechanistic-technical worldview in which God and reality are separated, but also with pantheism and a dynamic systems worldview blurring the boundary between God and the world. Dooyeweerdian thinking is based on a theistic worldview that distinguishes a personal God from created reality and relates God and reality in a living, continuous, and sustaining creator–creation relationship.

With the appearance of *In Search of an Integrative Vision for Technology*, edited by Strijbos and Basden (2006), the results of the latter program during its first decade have been documented. There are at least three important features that distinguish the interdisciplinary scope and character of this program. In the first place, interdisciplinarity concerns the shaping of a philosophical integrative framework that depicts the relationship between "technology" and "society," aiming for a normative-ethical basis to guide the development of science and technology for the benefit of society. For that purpose a systems view on "technology and society" has been conceived in which different systems levels are distinguished. A slightly adapted model that accounts for the differences between so-called developed and developing societies has been proposed in Rathbone et al. (2014, p. 6). With the help of this model it is possible to connect research—in engineering, management methodology, philosophy—on a specific systems level with research on other systems levels.

Second, an important part of the research program to which a number of people have contributed deals with the second realm of systems thinking, the study of practice-oriented systems methodologies for the fields of engineering and management. While making use of key notions of Dooyeweerdian philosophy, and in a critical conversation with hard, soft, and critical systems thinking, a new strand of systems thinking has been explored, labeled "multi-modal systems thinking" by de Raadt (1997) or "disclosive systems thinking" by Strijbos (2006).

Third, the research program involves a wide spectrum of disciplines and thus seems to fit nicely with what Boden has classified as integrated interdisciplinarity. It even takes this type of interdisciplinarity further, aiming to bridge the gap between the natural sciences and the humanities, and between theory and practice. Borrowing distinctions from

Frodeman and Mitcham (2007), the research can also be characterized as a "wide" and "deep" interdisciplinarity, a type of interdisciplinary research that aims to be "wide" rather than "narrow" and "deep" rather than "shallow." The narrow–wide distinction refers to whether only the natural and engineering sciences are involved or whether these are integrated with the human and social sciences. The shallow–deep distinction refers to whether interdisciplinarity is limited to scientific experts or whether people are also involved who are not academic researchers, but are experts with practical experience concerning real-world problems.

21.5 Conclusion

Around the turn of the century most of the founders of systems thinking passed away. Although some early representatives still play an active role, the future lies now with later generations. After reviewing in this chapter the more than 60 years of history behind us, these questions may be asked: What are the prospects of this movement? Is there a viable future for systems thinking with the execution of an innovation-oriented interdisciplinary scientific agenda? Besides organizational strength and resources, even more important for the future of any movement is to keep alive its spiritual-intellectual roots. With regard to the latter, it is important to note the role and ambitious agenda of the Bertalanffy Center for the Study of Systems Science (BCSSS) that evolved over time since 2004 and is located in 2013 in Vienna, the original home base of the father of systems thinking.

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CHAPTER 22

INNOVATION, INTERDISCIPLINARITY, AND CREATIVE DESTRUCTION

ROBERTO C. S. PACHECO, MAURICIO MANHÃES, AND MAURICIO URIONA MALDONADO

Innovation and interdisciplinarity have interesting commonalities. On one side, interdisciplinarity can be understood as an innovation on how to arrange disciplines to solve complex problems. On the other hand, innovation is a complex phenomenon that can only be described through multi-, inter-, and/or transdisciplinary perspectives. In this chapter, we discuss innovation, interdisciplinarity, and the fact that both are based on cyclical and creative processes of knowledge renewal.

The analysis of these commonalities has been present since the rise of innovation as a field of study at the beginning of the twentieth century. Since then, researchers and international organizations such as the Organization for Economic Co-operation and Development (OECD) and the World Bank have studied innovation, perceiving it not only as a technical process but also as an economic and, primarily, as a social evolutionary system. In this view, innovation is understood as an interdisciplinary phenomenon (Dosi et al., 2010; Dosi & Nelson, 1994). As a research object, it can be framed within a range of interpretations, allowing different disciplinary approaches and studies. Describing innovation through an interdisciplinary perspective can help tame apparently contradictory characteristics coming from (1) the timeliness of innovation as a social process and (2) the mechanistic regularities of capitalism's abstract forms (Sewell 2008). Therefore, it can be assumed that any academic approach to innovation demands designing research opportunities most often described as interdisciplinary.

Innovation and interdisciplinarity can be connected through several bridges, and with different lenses of analysis (including disciplines). As it will be presented below, two particular concepts are intrinsic to an interdisciplinary perspective about innovation: human plurality (Arendt 1981) and human cognitive interests (Habermas 1971). Based on these two concepts, we discuss the following relationships between innovation and interdisciplinarity: (1) innovation as an interdisciplinary phenomenon, (2) interdisciplinarity as an innovation to classical disciplinary systems, and (3) an integrative view between innovation and interdisciplinarity.

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22.1 Innovation as Interdisciplinarity

In order to explore innovation as an interdisciplinary phenomenon, first, it is of interest to understand it as an economic and a systemic phenomenon.

22.1.1 Innovation as an Economic Phenomenon

In the first decades of the twentieth century, driven by the Darwinian evolutionary metaphor, the Austrian-American economist and political scientist Joseph Schumpeter wrote that the childhood of every science is characterized by the prevalence of "schools," with each school claiming to be in "exclusive possession of Truth and to fight for absolute light against absolute darkness" (Schumpeter 1927, p. 286). Although Schumpeter himself did not explicitly relate innovation with interdisciplinarity, he knew that his view would be criticized by the conventional economic schools. In a paper titled "The Explanation of the Business Cycle" (1927), Schumpeter referred to different economic "schools" trying to explain the economic cycle. He reasoned that, although each of these "bodies of doctrine" stresses points of difference, "their results mostly point towards common goals" (Schumpeter 1927, p. 286). Therefore, he had already embedded into his work a much broader use of the concept of innovation than the economic one.

Nowadays it is accepted that, beyond having an "interschool" perspective toward explaining the business cycle, Schumpeter adopted an interdisciplinary attitude for finding explanations. Much sooner than the contemporary interdisciplinary perspective, Schumpeter had already expected that a convergent analysis and description of the business cycle could "co-operate in something like the spirit of physical science" (Schumpeter 1927, p. 287). Indeed, "there is something strangely, almost uncannily, repetitive in the changes" of the business cycle (Sewell 2008). While it is true that social processes are unpredictable, uneven, and discontinuous, "there is some central mechanism of capitalism that has remained essentially unchanged for a century and a half" (ibid). This contradictory characteristic of being both unpredictable and predictable is at the core of capitalism. Such reasoning opens up a wide horizon for interdisciplinary research about the business cycle. Nevertheless, although embedded with the spirit of physical science, Schumpeter was one of the first economists to associate innovation with a social phenomenon, evolutionary biology (Darwin 1860), and economic growth.

As a complex system, Schumpeter (1912, 1927, 1943) described the economic business cycle as a series of waves of economic depressions and booms. The latter is the result of reestablished equilibrium (business routine), as a consequence of actions developed by innovators who "rush ahead" (Schumpeter 1927), who then are followed by others as tried and tested new business routines start to crystallize and yield attractive profits. As soon as an equilibrium is established, more and more companies adhere to these new routines, causing profits to diminish. Due to the decrease of return on capital, "certain people" with certain attitudes (ibid), which we henceforth define as entrepreneurs, focus their "brain" on developing new combinations of factors of production. Schumpeter explicitly claims "there seems to be more 'brain' in business during depression" (ibid). And it is during depressions that errors are augmented by the fact that companies are acting outside of routine, and by acting in "a situation disturbed by action outside of routine" (ibid).

What is of note is the fact that during the previous equilibrium most of these errors would not have been considered errors at all but consequences and not causes of depression. It is "extremely probable," Schumpeter believes, that these recurring "crises" are an essential element of the capitalistic process and "not merely occasional breakdowns" (ibid.). Citing the French doctor and statistician Clément Juglar (1819–1905), the first academic to develop an economic theory of business cycles in 1862, he subscribes to the notion that "La cause unique de la depression c'est la prospérité" (Schumpeter 1927). This cyclical process of creative destruction, in his words, "is the essential fact about capitalism" (Schumpeter 1943, p. 83). However predictable is the incessant revolution of the economic structure *from within*, there is no point in appraising its performance at a given point in time. Its performance can only be judged over time "as it unfolds through decades or centuries" (ibid.).

What can be inferred from Schumpeter's definition of innovation is that it can be understood as a phenomenon that augments a social "potential" to act, echoing the very definition of knowledge as proposed by Krogh et al. (2013, p. 4). This potential can only be attained through a knowledge creation process (Nonaka et al. 2006). As described by Sewell (2008, 529), after "new combinations" (i.e., innovations) start to yield results,

> investments rush in, searching for enhanced profits; credit, employment and production expand in the area of innovation; meanwhile firms, regions or industries disadvantaged by the innovation experience the destructive side of creative destruction. Over time, the enhanced profits earned by the innovator will inevitably decline as others copy the innovation and scramble for their share of the spoils; credit will shrink as some of the new firms fail or are unable to meet earnings projections; and recession, local or general, arrives.

As described by Sewell (2008), there is a cycle between "new combinations" (i.e., innovations) and economic results. This allows us to see Schumpeter's view of innovation as the following cyclical process: (1) "brain" activities during crises; (2) followed by a series of experiments of new combinations; (3) that reach a new equilibrium, supported by new organizational routines; and (4) finally are copied by others. These routines, resulting from new combinations of production factors, can be considered as explicit knowledge obtained through a knowledge creation process (Nonaka et al. 2006).

Although economically viable new combinations may already be available as knowledge (scientific and/or other) or as invention, they may lie unused indefinitely. And that may be so "because doing what has not yet stood the test of experience is no mere act of ordinary business practice" (Schumpeter 1927, p. 293). And that unordinary business practice is a prompt for entrepreneurs, making them "certain people with certain attitude and aptitude" (ibid.).

Economic life goes on in "environmental isotropy" (Sarasvathy & Dew, 2005), an environment that changes and "by its change alters the data of economic action" (Schumpeter 1943, p. 82). Under such conditions of uncertainty, the economic cycle can be conceived as an evolutionary process, taken as a generative metaphor (Schön 1979). It is worth citing Dosi and Nelson (1994, p. 155) on how the underlying structures of economic science should be sought for in biology rather than in mechanics. They also noted "it is quite straight forward that one cannot construct a satisfactory theory of economic evolution simply by way of analogy with the biological model." Nevertheless, they believe, "the biological model might help illustrate the specificities of evolution in the social domain."

22.1.2 Innovation as a Systemic Phenomenon: The Neo-Schumpeterian Tradition

In the early 1980s, following the Schumpeterian tradition on the study of innovation and economic cycles, scholars began acknowledging the systemic nature of innovation, that is, the result of the interaction between users, producers, organizations, and institutions (Lundvall 1992). Even though, at the time, there was no direct mention of interdisciplinarity, this scholarly community—which later came to be known as neo-Schumpeterian—argued for the need to relate disciplines and to transfer knowledge between them, in order to produce innovations.

Several links between innovation and interdisciplinarity can be inferred throughout the works of the neo-Schumpeterian tradition. First is the "evolutionary" nature of economics through the innovation process, through the work of R. Nelson, S. Winter, and others. Second, that economic performance is the outcome of innovation, as was the case of Japan, and that many industry problems need to be solved by several industrial sectors working jointly, by means of technology transfer (Freeman 1987). And third, that innovation—when perceived as a system—is influenced by several types of agents, not only organizations, but also by regulations, legislation, and other territory- or sector-specific norms—known as institutions—and that, in many ways, they are the ones shaping or constraining interdisciplinary efforts.

Building on the three links previously described, the neo-Schumpeterian economic theory of innovation claims economic agents (firms, for example) do not behave as rational profit-maximizing ones, simply because they do not possess the whole information to make optimal choices. Agents, they suggest, are bounded-rational and therefore need to engage in cooperative activities with other market agents, in order to complement each other's weaknesses through, for instance, interdisciplinary problem-solving approaches.

Neo-Schumpeterian economists also suggest innovation is a systemic phenomenon (Lundvall 1992). It is not a random event but the result of coordinated interactions between many market agents, wherein learning activities take a fundamental role and both formal knowledge generation (through R&D, for instance) and informal knowledge generation (through learning-by-doing, for instance) are key processes. In fact, scholars from the neo-Schumpeterian tradition argue for learning by doing; using and interacting are in many cases even more important for the innovation process than formal modes, such as R&D (Jensen et al. 2007), indicating as well a need for interdisciplinarity.

On the other hand, technological development follows trajectories not necessarily along sectorial, national, or regional borders (Dosi 1982). Instead, they develop through the well functioning of a set of key activities[1] within the system, which may be performed by different types of agents from different sciences (e.g., disciplines) (Hekkert et al. 2007), incentivizing interdisciplinary research and development teams.

Recent applications of the "innovation as a systemic phenomenon" perspective and especially of the "technological innovation system" approach have been directed toward

[1] A sample set of such key activities might include, for instance (Hekkert et al. 2007): (1) entrepreneurial activities, (2) knowledge development, (3) knowledge diffusion through networks, (4) guidance of the search, (5) market formation, (6) resource mobilization, and (7) creation of legitimacy.

the study of the diffusion process of clean (renewable) energy technologies. This process is clearly a result of—or at least, dependent on—an interdisciplinary (and transdisciplinary) understanding of environmental, political, socioeconomic and technological issues.

22.2 Interdisciplinarity as Innovation

The first relation between innovation and interdisciplinarity is chronologic. The first historical recorded occurrences of what was called "innovation" by Schumpeter are from 1760 (Schumpeter 1927). The appearance of what Foucault called "scientific disciplines" occurred in the nineteenth century (1800), but their roots can be traced back to the previous one (Foucault 1975). Foucault named "disciplines" as the methods to control "bodies of men" in order to submit them to a "rapport de docilité-utilité" (Foucault 1975, p. 139). In Foucault's terms, disciplinarity dissociates power from bodies:

> Elle en fait d'une part une "aptitude," une "capacité" qu'elle cherche à augmenter; et elle inverse d'autre part l'énergie, la puissance qui pourrait en résulter, et elle en fait un rapport de sujétion stricte. Si l'exploitation économique sépare la force et le produit du travail, disons que la coercition disciplinaire établit dans le corps le lien contraignant entre une aptitude majorée et une domination accrue.[2] (Foucault 1975, p. 140)

Scientific disciplines evolve precisely, according to Foucault, to obtain *strict subjection* of a body of knowledge. He went further, claiming:

> La discipline est un principe de contrôle de la production du discours. Elle lui fixe des limites par le jeu d'une identité qui a la forme d'une réactualisation permanente des règles.[3] (Foucault 2014, pp. 37–38)

In that sense, scientific disciplines arise as a continuous updating of rules—as some kind of innovation—in the nineteenth century, giving birth to a period of disciplinary knowledge creation. As an innovation, disciplinarity enacted the precise dynamics of experimenting, reaching equilibrium and routines, which were then largely copied by other cognitive endeavors. Nevertheless, the "invention of disciplinarity" must not be seen as a "soudaine découverte"[4] (Foucault 1975, p. 140):

> Une multiplicité de processus souvent mineurs, d'origine différente, de localisation éparse, qui se recoupent, se répètent, ou s'imitent, prennent appui les uns sur les autres, se distinguent

[2] On the one hand, it turns it into an "aptitude," a "capacity," which it seeks to increase; on the other hand, it reverses the course of the energy, the power that might result from it, and turns it into a relation of strict subjection. If economic exploitation separates the force and the product of labor, let us say that disciplinary coercion establishes in the body the constricting link between an increased aptitude and an increased domination. (Translated by the authors)

[3] Disciplines constitute a system of control in the production of discourse, fixing its limits through the action of an identity taking the form of a permanent reactivation of the rules. (Translated by the authors)

[4] Sudden or unexpected discovery. (Translated by the authors)

> selon leur domaine d'application, entrent en convergence et dessinent peu à peu l'épure d'une méthode générale.[5] (Foucault 1975, p. 140)

In other words, as in the business cycle, disciplinarity arises out of countless combinatorial attempts until some equilibrium is reached and new routines are established. Therefore, as the counterpart in the scientific creative destruction cycle, as soon as disciplinarity reaches a *plateau* (Deleuze & Guattari 1987), certain entities start its "brain" activities, which in that particular phase would be interdisciplinary activities. It can be said that interdisciplinarity, at the present moment, represents innovation of the "scientific cycle."

Interdisciplinarity has as its underlying structure the concept of building bridges between different disciplines, which means not to solve the contradictions and incongruences between them, but rather to expand dialogue possibilities by building bridges. This definition, based on the generative metaphor of a bridge as a hermeneutical arc (Ricoeur 2007), is inspired by the French philosopher Paul Ricoeur and his insistence on building bridges between concepts that are seemingly incompatible.

If it follows the dynamics of innovation, interdisciplinarity will find its way through the traditional institutions of science and education, leading them to experiment with new combinations of structures. Then, following the cyclical process of creative destruction, after the emergence of these new routines academic institutions from all sorts will start to copy these structures. According to the innovation cyclical process, after reaching a new equilibrium *plateau*, new crises will start to germinate, putting the "brains" into the creative destruction activities once again.

In sum, perceiving interdisciplinarity as an element of a creative destruction process makes it possible to understand it based on the same elements proposed by Schumpeter for business innovation. From this point of view, interdisciplinarity is a "new combination" approach to the disciplinary way of researching, teaching, and practicing. In addition, as innovation in the business cycle, it arises in a moment of "crises" (scientific, environmental) and demands a concerted effort of brain activities, then a series of experiments, until reaches a new equilibrium. It is also straightforward to suppose that, as an innovation in the "scientific cycle," interdisciplinarity itself will start to be creatively destroyed as it reaches a plateau where it is adopted by organizations at large. So, the "disciplinary formations of modern science set the stage for further interdisciplinary interactions" (Frodeman & Mitcham, 2007), the same way that interdisciplinary formations set the stage for future disciplinary interactions.

22.3 In the Same Arendt/Habermas Light

Adopting the evolution process as a generative metaphor (Schön 1979) to approach innovation sheds new light onto its contradictory characteristic of being simultaneously creative

[5] It is rather a multiplicity of often minor processes, of different origin and scattered location, which overlap, repeat, or imitate one another according to their domain of application; converge; and gradually produce the blueprint of a general method. (Translated by the authors)

and destructive, both still and hypereventful. As a self-organizing phenomenon, creative destruction can make complex global patterns emerge from local interactions (Lansing 2003). In that sense, creative destruction results from attitudes and aptitudes that lead to interactions that "require creativity and energetic activity in order to create anything new of importance" (Schumpeter 1912). This reasoning draws the focus to the human capacity to create novel and relevant routines to a particular social context. In other words, it draws attention to creativity, a phenomenon related to both human plurality (Arendt, 1981) and human cognitive interests (Habermas, 1971).

22.3.1 Human Plurality

Creativity can also be metaphorically understood as an evolutionary process of blind variation and selective retention (Simonton 2010). According to Simonton (2010) and Ashby (1958), to generate creative solutions (understood as records of quality), a creative process must generate a considerable quantity of records altogether, that is, a diversified set of alternative solutions. A large quantity of diverse solutions will increase the possibility that one of them produces the invention of new technological artifacts, as new "means to fulfill a human need or purpose" (Arthur 2007), that is, to fulfill a human "cognitive interest" (Habermas 1971).

From a hermeneutical perspective, it is possible to describe innovation as a social process of understanding and sense making (Coopey et al. 1997). As such, innovation requires interpreting, envisioning, and generative interpretation (Verganti & Öberg 2013). As an understanding process, innovation requires the fulfillment of a certain human "cognitive interest." One key aspect in this process is the fact that it requires much more than a "tabula rasa": To "understand presupposes preunderstanding." Alvesson and Sköldberg (2009) also explain that preunderstanding is an obstacle to understanding. To prevent it from developing into a vicious circle, they advocated a "constant alternation between merging into another world and linking back into our own reference system" (Alvesson & Sköldberg 2009) toward a gradual revising and enriching of one's own.

Innovation, then, can only result from a group effort, departing mainly from previously accepted ideas and solutions, and usually focused (but not limited) on a single artifact, tangible or not. Whereas invention can be the result of an individual's work, innovation is a social process. Although the results of both can hardly be foretold, the commonly accepted notion is that a single person can achieve invention, but not innovation, precisely due to the fact that innovation occurs in a social context, requiring that a group of people perceives value in a particular artifact.

Viewing both invention and innovation as extremes of a continuum from "one" person to "many" stakeholders opens up the possibility making them less puzzling and ambiguous—to create a line of reasoning, and a metaphor, which will give a sense of what to expect and how to understand invention and innovation (Alvesson & Sköldberg 2009). To do so, it is possible to propose a matrix (in an interdisciplinary perspective) of two sets of concepts. One set represents a one-to-many continuum between individuality and human plurality. The other set is a possible perspective on the different human cognitive interests to control, understand, and/or criticize a specific artifact (tangible or not).

The first set follows the perspective of the German-born political theorist Hannah Arendt[6] (1906–1975). She considers *acting into the future* as a "We" not "I" effort—an action "in which a We is always engaged in changing our common world" (Arendt 1981, p. 200). By her own description, when she answers questions by Roger Errera[7] about a contemporary persistence of thinking based on historical determinism,

> Nobody knows what is going to happen simply because so much depends on an enormous amount of variables, as they say, that is, in other words, on the simple hazard. On the other hand, if you look back on history retrospectively, then you can, even though all this was contingent—you can tell a story that makes sense.

One of the many possible aspects that Arendt's view can bring to the concept of innovation is the perspective that, as a We-action into the future, it involves an "enormous amount of variables." Its predictability is forcefully lower than the one of an I-action that involves few variables. Another important aspect that can be apprehended from Arendt's words is the fact that innovation, as portrayed by the cited action continuum ("We" to "I"), only makes sense retrospectively. This proposed characteristic is aligned with Schumpeter's perception that the appraisal of the creative destruction performance can only be judged in its entirety as it unfolds through time (Schumpeter 1943). In other words, innovation is a sense-making process that "involves the ongoing retrospective development of plausible images that rationalize what people are doing" (Weick et al. 2005, p. 409).

Therefore, as Schumpeter has already pointed out, its evolution cannot be consistently prejudged. When writing about the process of creative destruction as an essential fact of capitalism, he thought that its performance can only be judged over time "as it unfolds through decades or centuries" (Schumpeter 1943, p. 83).

22.3.2 Cognitive Interests

The "I–We" continuum, taken as an interdisciplinary perspective on innovation, can be divided and ordered into a specific taxonomy. Human plurality ranges from an individual ("I") to a society ("We") through levels of the individual, team, group, organization, region, and nation. Although it is fundamental to establish such a taxonomy, which could be done by considering different aspects of coordination, cooperation, and communication (Kozlowski & Ilgen 2006), it is not possible to do so in the present chapter. Instead of detailing these different tiers of human arrangements, it is possible to understand innovation by considering what Schumpeter described as "brain activities"—that is, different cognitive interests that combinations of humans might have to innovate on.

Therefore, on the second set, a possible perspective on different human interest is presented, based on concepts related to human cognition. Habermas views knowledge in terms of what he defines as three cognitive interests (Alvesson & Sköldberg 2009): "a technical, a historical-hermeneutic, and an emancipatory interest."

[6] Hannah Arendt 1974's interview with the French writer Roger Errera. Retrieved June 23, 2014, from http://www.youtube.com/watch?v=b1u5OjatwqA, around 3'40".

[7] Roger Errera (1933–2014) was a former senior member of the Conseil d'Etat, France's Supreme Court for administrative law.

According to Habermas, innovation can be understood as a collective effort directed toward fulfilling human cognitive interests. Or, along with how Schumpeter describes it, to fulfill human cognitive interests is what needs to be done "in order to create anything new of importance" (Schumpeter 1912). Habermas explains (1971, p. 317):

> The specific viewpoint from which, with transcendental necessity, we apprehend reality ground three categories of possible knowledge: information that expands our power of technical control; interpretations that make possible the orientation of action within common traditions; and analyses that free consciousness from its dependence on hypostatized powers.

Although presented as separate, "there is a close relationship between the three varieties of cognitive interest" (Alvesson & Sköldberg 2009, p. 156). Technical knowledge empowers comprehension by interpretation and understanding (hermeneutics), and this leads to a critical position regarding the original point of view (emancipation). Emancipation is dependent on empirical-analytical knowledge to be able to understand the difference between what is given by nature and what is socially constructed. Habermas offers a perspective on Schumpeter's "brain activities" that can enable action toward further understanding of innovation. By coupling Arendt's and Habermas's perspectives, a more predictable landscape of innovative efforts emerges.

22.3.3 Enabling to Act

The two perspectives of Arendt and Habermas can be assembled in a way that creates a line of reasoning that gives us a sense of how predictable the process of innovation is, based on (1) how many people are involved and (2) which type of human interest it will serve. Table 22.1 depicts this reasoning.

The cells in Table 22.1 represent features that have the level of predictability change with I or We, in the three kinds of cognitive interests. Based on the proposed relations between cognitive interests and the amount of human plurality involved, it is possible to claim that innovation can range from a low-predictability perspective on the lower-right corner (We-Emancipatory), to a high-predictability perspective on the higher-left corner (I-Technical).

The level of predictability relates to the concept of understanding. One of the definitions of the latter is "to be able to predict." Thus, understanding a particular phenomenon entails "establishing similarities, regularities and conformities to law which would make it possible to predict individual phenomena and processes" (Gadamer 2004, p. 3). When a phenomenon is perceived as being understood, the main result of this understanding is the capacity to predict its behavior or consequences. Understanding innovation through different levels of predictability allows devising better approaches for individual or collective endeavors. In a sense, it enables social contexts to commit to action (Weick et al. 2005).

Even though highly predictable, innovative endeavors should not be based solely on technical innovations (product innovations, process innovations, organizational innovations, and marketing innovations), as proposed by the OECD. In terms of the Arendt/Habermas frame, the proposed OECD classification covers only I-Technical and We-Technical categories. It leaves uncharted—and OECD's model is unaware of—all innovation initiatives that are not technical, such as social innovation, to name but one.

Table 22.1 Cognitive Interests, Quality/Quantity, and Predictability

	Technical	Historical-Hermeneutic	Emancipatory
"I"	**High Predictability** • Individual interests • Few variables • Individual sense-making	**Medium/ High Predictability** • Expand possible interpretations • More variables • Reduce prejudice	**Medium Predictability** • Critically oriented science • Free consciousness • Meta-routines to ad hoc approaches
"We"	**Medium Predictability** • Empiric-analytic sciences • Expand technical control • Search for customizable routines	**Medium/ Low Predictability** • Historical-hermeneutic sciences • Common traditions (collective memory) • New interpretations: sense-making; storytelling; system and design thinking. • Meta-routines to ad hoc approaches	**Low Predictability** • Critically oriented sciences • Free and collective consciousness • Collective interests • Several variables; Complex global patterns and Collective sense-making • Records of quantity

Source: Based on Habermas and Arendt, as cited above.

Instead, an interdisciplinary approach should enable different perspectives of cognitive interests to intellectually understand the "mysteries" of innovation. By doing that we believe that it is possible to augment the potential of organizations to act.

These potentialities to act should reach beyond disciplinary technicalities and support wide interdisciplinary understanding that put under the same light seemingly disparate innovative initiatives. This is precisely what the frame in Table 22.1 enables people to do. Bridging different innovative initiatives through their expected levels of predictability—their levels of *docilité* to be understood—theoretically should enable organizations to devise better approach methods for each specific innovative effort. Efforts can be executed, at the extreme I-Technical, to generate records of quality. At the other extreme, the We-Emancipatory, records should be produced in quantity.

22.3.4 A Conceptual Framework for Innovation

As can be seen, innovation has been historically conceived as a complex phenomenon that is intrinsically interdisciplinary. Since there are several lenses of analysis, there is no consensus on the definition of innovation. Different definitions have been proposed according to several purposes.

Innovation has been defined to be comparable among countries or regions (such as the OECD definition), to be studied as a systemic phenomenon (e.g., "the collaborative recombination or combinatorial evolution . . . of practices that provide novel solutions for new or existing problems"; Vargo et al. 2015, p. 70), or to be pragmatically adopted by innovative firms (e.g., "successful creation and delivery of new or improved product or service in the marketplace. Or to put it in another way, innovation is the process that turns an idea into value for the customer and results in sustainable profit for the enterprise"; Carlson & Wilmot 2006, p. 4).

Regardless of the definition we choose, there is a consensus that innovation depends on several players, factors, and dimensions. This is why innovation became an object of study and practice of several approaches, sources, and fields.

As this chapter's last effort, based on the Arendt/Habermas perspective and the commitment to enabling readers to act into the future, we propose a conceptual framework for perceiving innovation from an interdisciplinary perspective. Of course, as advocated by the French philosopher Paul Ricoeur, this interdisciplinary conceptual framework relies on its "faiblesse épistémologique"[8] (Ricoeur 1986, p. 315) to draw the necessary force to break new ground.

To better apply the potential to act offered by the proposed framework, it is necessary that its users first adopt a specific definition of what they understand by innovation (see Table 22.2). As an example, we adopted the pragmatic definition of Carlson and Wilmot (2006). Based on this contextually chosen definition, the framework structure presents five columns in a particular sequence: Components (What), Mechanisms (How), Stakeholders (Who), Goals (Why), and Locus (Where).[9]

In the first column, there is a list of components (constructs) fundamentally related to innovation. These components represent different elements in the innovation process, including knowledge and information (from several sources and nature), that play a central role to generate ideas, which can be transformed into improvements or inventions that might have an impact on technology creation, and other forms of novelties, hopefully perceived as values by a social context. In sum, innovation comes from several factors that range from creativity to value perception, and result from processes such as ideation, inventing, researching, understanding, designing, creating knowledge, and solving problems. Depending on the adopted definition, some of these concepts are more relevant than others (e.g., ideas and values are explicitly important to Carlson and Wilmot's [2006] definition). This column also includes institutional factors that impact on innovation on a particular system (regulations, business rules, and culture).

The second column has five sets of instruments (mechanisms) to perform or study innovation: (1) disciplines, (2) frameworks, (3) processes, (4) learning, and (5) expected features. The first set has some of the disciplines (and subfields) that offer knowledge to innovation, ranging from arts to social sciences to engineering and technology. Theoretical and practical frameworks for understanding innovation form the second set of instruments. These

[8] As translated by the authors: "epistemological weakness." This expression appears in the following excerpt: "La théorie sociale globale serait dans le même rapport avec l'idéologie si elle pouvait satisfaire aux mêmes critères que ces sciences positives. Or la faiblesse épistémologique de la théorie sociale globale est à la mesure de la force avec laquelle elle dénonce l'idéologie" (Ricoeur 1986, p. 315).

[9] Although we are aware that the 'Five Ws and One H' heuristic finds no epistemological support and has been considered a fallacy since the 1940s, our commitment to enabling readers to act allowed us to superimpose this heuristic at the proposed framework as a mnemonic tactic.

Table 22.2 Framework: Interdisciplinary Perspective on Innovation

Components (What)	Mechanisms (How)	Stakeholders (Who)	Goals (Why)	Locus (Where)
Definition Innovation is ["*Successful creation and delivery of new or improved product or service in the market place. It is turning ideas into value for customers with a sustainable business model for the enterprise producing it.*" Carlson & Wilmot (2006)] **Constructs** Knowledge Information Idea Improvement Invention Technology Novelty Value **Institutions** Legislation Norms Business rules Culture	**Disciplines** Arts Architecture Business administration Design Economics Entrepreneurship Education Engineering Law/IP Knowledge management Psychology and cognition Systemic thinking System theory Technology *[Innovation domain]* **Frameworks** Academic research Agencies (OECD, WB) **Processes** Problem solving Creativity/ideation Understanding R&D Design Planning/Management Commercialization Assessment Legislate Subsidize Financing **Learning** By-doing By-using By-interacting By-imitating By-internal search By-external-search **Features** Sustainable Open Incremental Disruptive Radical	**Individual Agents** Researchers Domain Experts Inventors/Authors Designers Entrepreneurs Managers Salespeople Sponsors Costumers **Collectives of Individuals** Project teams R&D Groups R& Networks Crowd innovators **Organizational** Firms Government Universities R&D Institutes/Labs Social organizations Agencies Incubators **Collectives of Organizations** Associations Virtual organizations Conglomerates Clusters Innovation parks Networks	**Organizational Goals** Structural improvement Technological improvement Intellectual property Employment Marketing Social value Profits **Collective Perspective** Educational Social Cultural Artistic Economic Technological **General Impact** Economic Social Educational Cultural Environmental	**In Organizations** Process Product Technology Market Business model Organizational structure Relational capital **In Sectors** Industrial Energy Agribusiness Health Education Law Services Economy Politics Governmental Arts **In Geo Systems** National innovation Regional innovation Local innovation

frameworks are designed by academia and agencies (such as the OECD or World Bank) to measure innovation in companies or regions. The third set includes innovation phases, from problem solving/ideation to financing. The fourth set contains all learning modes applied to innovation processes, and the last set has different forms of characterizing innovation in terms of life cycle (i.e., if sustainable), protagonist strategy (open × closed/isolated) or market impact (incremental, disruptive, or radical).

The third column represents the innovation players (Stakeholders). First, innovation depends on individuals (such as researchers, experts, inventors, entrepreneurs, managers, designers, sponsors, and customers), teams (such as specific project teams), groups (such as R&D groups), networks, or even crowd innovators. Additionally, innovation occurs as a combination of organizations with complementary missions in the innovative system. This includes single organizations (firms, universities, R&D labs, incubators, and government such as public funding agencies) and their collectives (such as associations, virtual organizations, clusters, parks, and networks).

The fourth column lists three scenarios to analyze innovation goals. In organizations, innovation can aim to create intellectual property, better employment, marketing position, and social value and, most importantly, to improve general results. On the other hand, collectives of individuals can search for innovation projects motivated by educational, social, cultural, artistic, economic, or technological reasons. National or regional programs can be designed by innovation funding agencies to pursue more general impacts, such as economic, social, educational, cultural, or environmental developments.

In the fifth column, there are three nonexclusive innovation loci: organizations, collectives, and economic sectors or geographical systems. In the first case, innovation is an organizational strategy to evolve (processes, products, marketing, technology, business model, or relationships such as social responsibilities). Innovation can also happen as a response to sectorial demands such as industrial, energy, health, education, or public needs. When conceived as a geographical dynamic system, innovation results from national, regional, or local systems of organizations.

In sum, this conceptual framework illustrates the fact that innovation has several players, perspectives, elements, and lenses of analysis (including disciplines). There is no space here to analyze each one of its components, given the extended account of each variation in the literature. Our intention has been to demonstrate the multi- and interdisciplinary nature of innovation.

22.4 Conclusion

Innovation and interdisciplinarity share commonalities and reciprocal effects. As examples of these commonalities, innovation and interdisciplinarity are both susceptible to a process of creative destruction of knowledge. Both arise in a moment of "crises" (scientific, environmental), demanding a concerted effort of brain activities, then a series of experiments until reaching a new equilibrium. It is worth mentioning that the almost simultaneous historical appearance of both should call for further investigations in the future.

Here we propose an "I–We" continuous view to the process of individual to social actions. We have shown that social actions are enacted differently as their specific deliverables differ regarding the related cognitive interests and human plurality. Theoretically, the planning of an interdisciplinary effort done by taking this Habermas/Arendt perspective should yield more predictable results. If nothing else, just considering the level of predictability of actions located in different dimensions would make the set of interdisciplinary research goals more attuned to effective possibilities of accomplishing them. Interdisciplinary efforts, as actions into the future, should take into account these six dimensions (see Table 22.1) in order to have the power of understanding what organizations *can know, ought to do* and *may hope*[10] to accomplish, as it is especially the case of innovation.

As we have described, being a result of interdisciplinary efforts, innovation is a multifaceted phenomenon, with several sources, protagonists, motivations, instruments, and results. In organizations, its ultimate goal is to augment the potential to act into the future. As we have shown in the conceptual framework, innovation can be defined, located, performed, and studied according to several dimensions. Interdisciplinarity, on the other hand, proposes new arranges of knowledge and new forms of making scientific disciplines contribute to solve complex problems. As an innovative process, interdisciplinarity has a myriad of factors and actors.

The conceptual framework presented in this chapter brings the possibility of an integrative analysis between innovation and interdisciplinarity. In such analysis, interdisciplinarity is conceived as an innovative process in science development. The analysis starts by the conceptual constructs of interdisciplinarity. So, in the column "What" would be topics such as knowledge and institutional components of interdisciplinarity (e.g., the values interdisciplinarity offers to scientific development). The second column ("How") would have interdisciplinarity mechanisms such as fields of knowledge, frameworks, processes, characteristics, degrees of integration, and contrasting types (see Klein, this volume). Interdisciplinarity stakeholders (e.g., researchers, professors, managers, technicians, citizens) would compose the third column ("Who"). In the "Why" column would be the reasons why interdisciplinarity has been proposed as a contemporaneous mode of knowledge production. And last, but not least, such integrative study would also list the locus of interdisciplinarity (e.g., universities, public agencies, research groups). Many of these subjects are extensively discussed in this volume.

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[10] "The whole interest of reason, speculative as well as practical, is centered in the three following questions: 1. What can I know? 2. What ought I to do? 3. What may I hope?" (Kant 1855, p. 488).

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CHAPTER 23

ADDRESSING WICKED PROBLEMS THROUGH TRANSDISCIPLINARY RESEARCH

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Addressing real-world problems is one of the purposes of integrative and collaborative research. Transdisciplinary research (TR) is a family of concepts and approaches that aims at better fitting academic knowledge production to societal needs for solving, mitigating, or preventing problems such as violence, disease, and environmental pollution. Transdisciplinary research strives to grasp the relevant complexity of a problem, taking into account the diversity of both everyday and academic perceptions of problems, linking abstract and case-specific knowledge, and developing descriptive, normative, and transformative knowledge for the common interest. Integration is a core feature and major challenge of TR. Practitioners of TR also call for a recursive approach to addressing problems, focusing on problem identification and structuring, investigation, and bringing results to fruition as the three phases of the TR process.

In this chapter we first describe the context in which TR and kindred approaches emerged in the second half of the twentieth century and the steps in developing TR as a form of research (Section 23.1). We then present a definition of TR that focuses on its role in addressing wicked real-world problems (Section 23.2). Next we explain challenges that come along with research on real-world problems (Section 23.3) and with providing knowledge for addressing such problems (Section 23.4). Tools for tackling challenges of the TR process appear after that (Section 23.5), illustrated by the example of the Sustainability Foresight project. The conclusion highlights open questions and ongoing debates requiring clarification for the next steps forward in TR (Section 23.6).

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23.1 Background

Academic research is an integral component of the knowledge society as it developed across the twentieth century. Stokes defines the leading paradigm for the science-practice interrelation after World War II as a linear model that embodies "the belief that scientific advances are converted to practical use by a dynamic flow from science to technology" (Stokes 1997, p. 10). The linear model is based on the idea of a one-way transfer of allegedly reliable knowledge from experts to "ignorant" users (Wynne 1993). Scientific theories and models idealize and simplify complex relations in order to make them scientifically treatable, in, for instance, molecular and microbiological mechanisms, patterns of epidemiological spread underlying infectious diseases, and the *homo oeconomicus* model. This approach means that such theories and models only address selected aspects of societal problems. Moreover, measures and technologies developed according to the linear model run a high risk of unexpected side effects, if they do not account for relevant factors in the context of application. Toward the end of the twentieth century the risks of modern science and technology triggered a debate about the need for a more reflexive relationship between science and the knowledge society (Beck 1996).

This debate formed the backdrop for a new sense of transdisciplinarity that emerged in the 1970s, as questions were raised concerning the orientation of knowledge production in research, education, and public and private institutions. Concerned systems scientists such as Erich Jantsch and philosophers such as Joseph Kockelmans initiated a debate about how to deal with complexity and value issues related to human activities (Apostel 1972). Developments in the history of science, humanities, and social sciences have further nurtured debate on conceptualizing transdisciplinarity over the years, including notable examples of (1) systems approaches (Stribos, this volume), and (2) theories of social action and learning following the interpretive paradigm in social research and including action research.

1. A systems approach for conceiving of complexity was developed as early as the eighteenth century by Johann Heinrich Lambert, who proposed to structure complexity as a set of interrelated elements and applied his approach to structures of scientific knowledge and to belief systems of cultures, religions, and narratives, including systems constructed to realize desired states. Systems theory did not become a blueprint for structuring complexity until the twentieth century, against the background of progressive fragmentation of science into more and more specialized disciplines and thematic fields (see Strijbos, this volume).
2. Debates on how to properly theorize social action and learning date back to the dissociation of humanities and social sciences from philosophy starting in the nineteenth century, when the social effects of industrialization and migration gave rise to sociology in Europe and America. Innovative developments such as the Chicago School of sociology in the United States, and Max Weber's interpretive sociology in Germany, laid the grounds for an interpretative paradigm in social research. Interpretative social research investigates and reconstructs the meaning people attribute to empirical phenomena, institutions and agency in the form of a grounded theory or of ideal-types. In TR, these methods are particularly relevant for bridging idealized theories or models and concrete problem contexts (see Krohn, this volume), and for investigating and interrelating normative, transformative, and empirical knowledge. Action research has

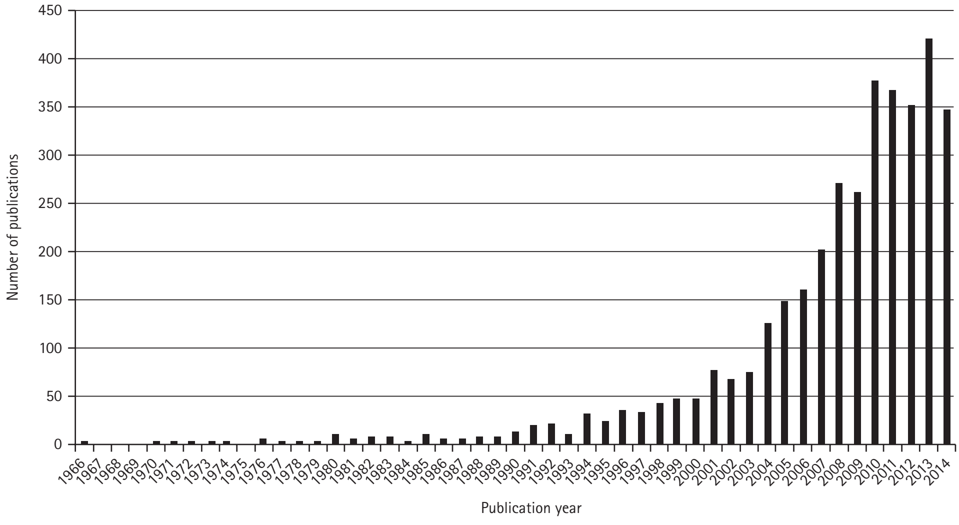

FIGURE 23.1 Numbers of publications that include "transdisciplinary" or "transdisciplinarity" in the topic. The search was performed through Web of Science on January 16, 2015 (http://www.transdisciplinarity.ch/en/td-net/Literatur/Publikationsradar.html). The decline in numbers in 2014 is very likely due to papers not yet included in the Web of Science database.

> emerged more recently. It aims at mutually benefiting theory and practice in understanding and dealing with societal problems. Action research starts with people's interpretation of reality, basing research in the field to learn about the consequences of social action. The people studied should both be researched and research themselves, linking the interpretive paradigm with one of the central tenets of TR in this chapter: the engagement of stakeholders in the actual process of research.

Being shaped by these and further lines of thinking, the new connotation of TR in Europe started in the 1990s in environmental research programs in Switzerland, Austria, Germany, Sweden, and the Netherlands (Bunders et al. 2010). In contrast to earlier definitions that prioritized theory, in these research programs researchers of different disciplines and societal actors collaborated to coproduce knowledge on real-world problems. Today, the international research initiative "future earth" is also promoting coproduction of knowledge by science and society.[1] Figure 23.1 documents an increased interest in, and exploration of transdisciplinarity in research by the growing number of publications.

23.2 Defining Transdisciplinary Research

The term "transdisciplinarity" is disputed and used in different ways. These ways, and how they relate to the meaning of terms such as "multidisciplinarity" or "interdisciplinarity" can be distinguished by referring to the purpose of research. Depending on purpose, the kind

[1] See http://www.futureearth.org/themes/transformations-towards-sustainability.

and degree of integration and the elements to be integrated differ. The purpose of multi- and pluridisciplinary research is not to integrate information but to provide a comprehensive collection of information from different fields on a given subject. Multidisciplinarity is a valuable means to opening up different aspects of a subject, preventing falsely prioritizing only one specific perspective. Inter- and transdisciplinary research explicitly attempts to integrate the plurality of information. Accordingly, the US National Research Council defines interdisciplinary research as "a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice" (NAS/NAE/IOM 2005, p. 188).

Integration comes in degrees: On the one end, insights from different perspectives are interrelated without changing them, and on the other end, "fundamentally new conceptual frameworks, hypotheses, and research strategies that synthesize diverse approaches and ultimately extend beyond them to transcend preexisting disciplinary boundaries" are created (Stokols et al. 2013, p. 5; see also Klein, this volume). The National Academies' definition of interdisciplinary research distinguishes two purposes for knowledge integration: (1) to advance fundamental understanding and (2) to solve problems. For both purposes, insights from different disciplines need to be integrated in order to account for the diversity and complexity of the studied phenomena. In the case of advancing fundamental understanding, general theories or models and new methods are developed by combining elements from different disciplines in order to examine scientific problems that lack explanation. In the case of problem-oriented research, researchers from various disciplines and representatives of diverse societal groups are brought together to integrate scientific knowledge with other perceptions of what the problem is about and how it should be tackled to address the complexity of real-world issues.

The first case, however, is still relevant to the conception of transdisciplinarity. Within advancing fundamental understanding, we suggest distinguishing between the purposes of scientific innovation and holistic understanding. Scientific innovation aims at advancing fundamental understanding—for instance of emotions—by means of developing and examining general theories, models, or hypotheses about processes that lack explanation. The purpose of holistic understanding is also relevant. Here, scholars conceive of transdisciplinarity as a way of interrelating Western scientific and traditional ways of knowledge, for instance in the field of health (Martin 2012). For the same reason, other scholars search for universal formal structures or patterns in the pluralistic reality, and for ways to transcend this inherent plurality (Nicolescu 2010).

In this chapter we focus on the second case, solving problems as a form of knowledge integration with the purpose of addressing real-world problems of society. We define TR by the way it addresses such problems: TR strives to grasp the relevant complexity of a problem, taking into account the diversity of both everyday and academic perceptions of problems, linking abstract and case-specific knowledge, and developing descriptive, normative, and transformative knowledge for the common interest. In the European context—specifically in the German-speaking part of Europe—"transdisciplinary research" has become the familiar term for such problem-oriented research. In addressing real-world problems, though, we have to distinguish "tamed" from "wicked" problems (Rittel & Webber 1973, p. 160). Tamed problems have a clear goal or mission (e.g., solving a mathematical equation, analyzing the chemical structure of a compound, building an atomic bomb) and proposed solutions can clearly be judged as success or failure. A problem is tamed if addressing it does not include questioning the mission, or whether the problem should be addressed at all. Tamed problems are solved either by specifying and adapting the knowledge of the disciplines and fields relevant for the problem at hand or by carrying out use-inspired basic research if innovation is required, such as for building the atomic bomb or landing on the moon.

In contrast, addressing societal problems usually includes deliberating what the problem is about, and whether, and how, and by whom it should be addressed. Rittel and Webber (1973, p. 155) conceptualize such problems as wicked design problems. They differ from tamed problems in several ways:

1. They are not well-defined; i.e., every formulation of the problem is already made in view of some particular solution principle. [. . .]
2. For design problems there is no criterion which would determine whether a solution is correct or false. These are meaningless labels which cannot be applied to solutions of design problems. Plans are judged as good, bad, reasonable, but never correct or false. And a plan that looks good to Mr. A may be most objectionable to Mr. B.
3. For design problems there is no rule which would tell the designer when to stop his search for a better solution. (Rittel 1971, p. 19)

Climate change is an instructive example of dealing with a wicked problem. Climate change is, among others, framed as a problem of (1) molecules in the atmosphere that have to be reduced or (2) can be geo-engineered, for example, by emitting sulfur aerosols into the atmosphere; a problem of (3) the wrong prices for coal and oil; (4) public misunderstanding of the risks of nuclear power; (5) too much mobility of humans and products, or (6) as no concern at all. Policies to deal with climate change are not right or wrong as such, but good or bad, reasonable or inappropriate in the light of a specific framing. Here too, a policy that looks good to one person may legitimately be opposed by another who frames the problem in a different way. And finally there is no rule about when to stop, because every solution to climate change possibly will have unintended side effects and create new problems.

23.3 Challenges of Wicked Problem–Oriented Research

Problems in dispute across society such as violence, hunger, poverty, disease, and environmental pollution are called wicked because those involved—academic researchers as well as nonacademic actors—may not agree on either the relevance of the problem and what is at stake, or on its causes and consequences, or on the type of strategy required. Not surprisingly, wicked problems also resist definitive solutions and are characterized by uncertainty and unwanted side effects. As a result, they call for recurrently adapting measures based on how the problem changes. To account for these challenges, TR defines knowledge production in terms of four fundamental requirements: "TR deals with problem fields in such a way that it can (a) grasp the complexity of problems, (b) take into account the diversity of scientific and life-world perceptions of problems, (c) link abstract and case-specific knowledge, and (d) develop knowledge and practices that promote what is perceived to be the common good" (Pohl & Hirsch Hadorn 2007, p. 20). A transdisciplinary research project can be structured as a system with elements of the problem field, academic researchers, and nonacademic actors. The term "system" refers to the interaction of these elements during the research process, namely by discussing what the problem is about, by investigating the problem, by deliberating about values and goals, and by developing strategies and measures to address the problem. Nonacademic actors and academic researchers interact with the shared aim to improve a particular situation in a problem field.

The policy cycle is a simple model of how society addresses a wicked problem (deLeon 1999). The four stages are (1) problem framing, (2) policy development, (3) policy implementation, and (4) policy evaluation (see Figure 23.2). Again simplifying, the societal process taking place during these stages can be seen as the interplay of four policy cultures: the public sector, the private sector, civil society, and academia (Elzinga 1996). Each culture participates in that process through its power, expertise, and interests. If academia enters such a process in a transdisciplinary project, the kind of knowledge it has to provide changes depending on the stage of the policy cycle. During problem framing, for instance, TR requires contributing to a comprehensive understanding of the problem. When developing policies, however, TR has to provide knowledge about the means to change the current situation and about the intended direction of change (see 23.4).

Wicked problems further require the mission or goal of the transdisciplinary project to be deliberated by those participating in the project. Here the requirement that TR is promoting the common good comes into play. Promoting the common good has been understood as the goal of the state or community as opposed to private interests. In TR and related fields, the common good is used in a similar way, to bring discussion from the level of individual interest to the level of collective interests. The "common good" is the general concept further specified in transdisciplinary health research as "public health" (see chapter on public

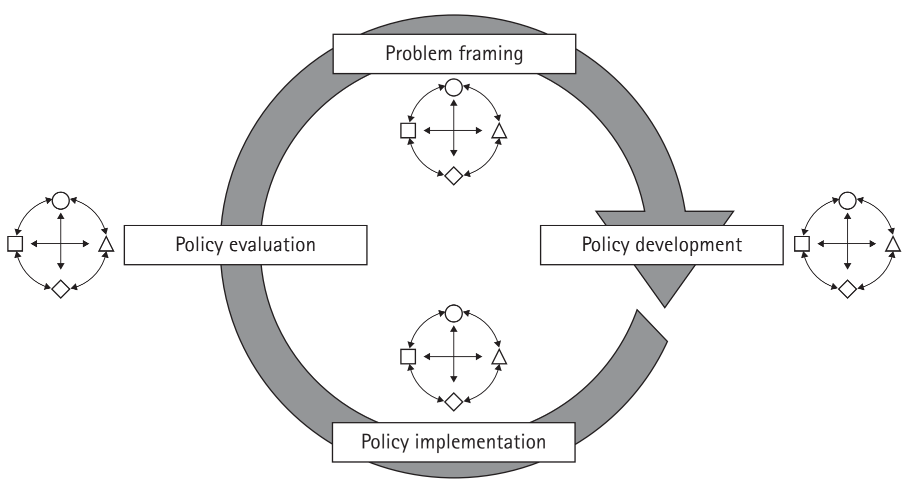

FIGURE 23.2 Simple four-stage approach to the policy process. A policy process and its outcome is the result of the continuous interplay of different policy cultures: the public sector (triangle), the private sector (diamond), civil society (circle), and academia (square) (Wuelser et al. 2012, p. 86).

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health) or in sustainability science as "sustainable development" (see Fernandes and Philippi Jr, this volume).

The common good serves as a regulative idea when deliberating the mission, namely, by reflecting on controversial normative orientations that can be taken toward the wicked problem. As a sociopolitical ideal, it is open to various interpretations that resist unification. Because of this pluralism, neither a particular theory such as utilitarianism nor a particular position in society such as being a pastor or politician entitles anyone to definitively define what terms such as "common good," "public health," or "sustainable development" mean in a given situation and for its improvement. So, how to analyze and specify the common good in view of the particular wicked problem is one of the research questions to be addressed in providing normative, descriptive, and transformative knowledge.

23.4 Types of Knowledge for Addressing Wicked Problems

The challenges of wicked problem–oriented research come along with the different types of knowledge TR has to provide. Swiss researchers suggested distinguishing three such types of knowledge (ProClim 1997):

- Knowledge about what is (systems knowledge)
- Knowledge about what should be (target knowledge)
- Knowledge about how to come from where we are to where we should be (transformation knowledge).

In the case of climate change, for instance, systems knowledge helps to understand the phenomenon of climate change, its causes and consequences, and also how different groups in society perceive the phenomenon. Systems knowledge is what research mainly provides in the stage of problem framing, when society is becoming aware of a problem and debating how to frame it (see Figure 23.2). Target knowledge helps in deliberating on the goal. Shall we mitigate climate change or adapt to it? Based on what considerations—for example, a fair distribution of costs and benefits among the living—shall this decision be taken, and by whom? Transformation knowledge answers the question of what legal, technical, economic, cultural, or other measures there are to reach the goal decided on. Both target and transformation knowledge are mostly required for the stages of developing and implementing policies.

To produce useful results in TR, the interdependences between the three forms of knowledge must be taken into account. For example, to develop climate policies (transformation knowledge) one has to know or assume what state of future climate we are aiming at (target knowledge) and how the climate system works (system knowledge). Depending on whether the target is an atmosphere with a lower concentration of greenhouse gases, or an atmosphere heating less, such policies would have to lower the emission of greenhouse gases on Earth in the first case while, in the second case, geo-engineering would be among the options to choose from. Furthermore, policies to lower emissions need to adapt to new system knowledge about sources such as methane emissions of livestock.

23.5 Next Step: Assigning Tools to Challenges

To avoid overburdening TR projects, two tasks are important: (1) to reduce complexity by specifying who needs what knowledge and (2) to achieve effectiveness through contextualizing the project within science and society (Pohl & Hirsch Hadorn 2007). For these purposes, the TR process includes two more phases than a disciplinary one (see Table 23.1). Before specific research questions are analyzed in detail (phase 2), an appropriate team has to be formed and the problem has to be framed and conceptualized (phase 1). After detailed analysis, what has been learned has to be promoted within science and society (phase 3) for further experience and recursive adaptation.

For instance, in phase 1 of a TR project on climate change, the team of researchers and societal actors has to define the specific aspects of climate change to be analyzed and whether systems, target, or transformation knowledge is most needed given the current situation. Depending on how the problem is framed, the composition of the team might have to be reviewed. Phase 3, finally, serves to bring what was learned within the project team to a broader audience and to "test" the insights gained. The testing might not provide the intended change, or come along with unintended side effects, leading back to phase 1 and to a new attempt to frame the problem.

All three phases of a transdisciplinary research process present challenges that researchers working within a discipline may not be familiar with. Over the last years various methods and tools to tackle the challenges have been developed (see e.g., O'Rourke, this volume). More recently, online collections have been made available, such as the team science toolkit (www.teamsciencetoolkit.cancer.gov), the integration and implementation science tools (http://i2s.anu.edu.au/category/resource-type/tools) and td-net's toolbox for coproducing knowledge (www.transdisciplinarity.ch/toolbox). Each tool usually addresses a very specific challenge. The next major step TR has to make is to systematize the challenges researchers are confronted with during a TR process and to assign the various methods and tools available to these challenges (McDonald et al. 2009; Bergmann et al. 2012).

Table 23.1 Phases of the Transdisciplinary Research Process According to . . .

	. . . Pohl & Hirsch Hadorn (2007)	. . . Jahn et al. (2012)	. . . Hall et al. (2012)
Phase 1	Problem identification and structuring	Formation of a common research object	Development of team Conceptualization of research
Phase 2	Problem analysis	Production of knowledge	Implementation of research
Phase 3	Bringing results to fruition	Transdisciplinary integration	Translation of results

For example, the "Three types of knowledge tool" of td-net's toolbox for coproducing knowledge is useful in phase 1 of TR. It helps to reveal the type of knowledge (see Section 23.4) researchers have in mind, when formulating research questions, and to reformulate the questions to account for the overall aim of the project. The tool works as follows: Early in phase 1 researchers of a TR project are asked to formulate what they see as the main research question, either individually or in groups. They then are introduced to the three types of knowledge and asked what type of knowledge is most applicable to answering their research question. Thereafter, they are asked to reformulate their research question in a manner so that answering it would provide each of the three types of knowledge. To illustrate:

- How do visualized brain activities relate to the health of epilepsy patients? (Systems knowledge)
- What is improved health in epilepsy patients? (Target knowledge)
- How will visualization of brain activities improve the health of epilepsy patients? (Transformation knowledge)

Usually the reformulation triggers a discussion (or individual reflection) on the overall aim of the project and whether the research will help to reach that aim. For instance, the aim of TR is often to provide transformation knowledge. Researchers usually formulate the research question to provide systems knowledge. Target knowledge is often taken as self-evident (see also example of the Sustainability Foresight project, discussed below).

Researchers usually struggle most with formulating that question. However, for addressing wicked problems, it is key to realize that the specific understanding of the target (What do we mean by a sustainable climate system? What do we mean by improved health in epilepsy patients?) can be contested among the researchers and social actors involved. The tool triggers the reformulation of the research question—but not necessarily based on consensus among participants. It might also clarify the specific contribution of subprojects or point to concepts that still have to be defined for the whole project (e.g., a more sustainable climate system or improved health in epilepsy patients).

23.6 Open Questions and Ongoing Debates

Transdisciplinary research is a form of research that is defined by social and cognitive integration in relation to a specific purpose. With the purpose of dealing with wicked problems, TR differs substantially from the standard form of research. Although a considerable stock of competencies and knowledge has grown in the last decades, the major scientific, institutional, and societal challenges are still the same identified by Wiesmann et al. (2008). Add-ons to the standard form of research are one means of contributing knowledge for dealing with problems in society. Such knowledge might be very helpful for tackling tamed sustainability issues, but not for wicked ones. Hence, elaborating TR as a form of research requires better distinguishing TR from standard research with add-ons. Four crucial questions loom large for future research:

- How does the impact of TR differ from "outreach" of standard research? "Outreach" uses communication to encourage use of results. While appropriate communication is important, it does not substitute for coproduction. In the coproduction of knowledge, effectiveness of research for addressing real-world problems is achieved by communication with relevant nonacademic cultures through all phases of the research process in order to consider their interest, power, and expertise on the issue at hand for knowledge production.
- How does integration in TR differ from standard research integrated at the "end of the pipe," in the form, for example, of providing a summary of results independently from each other? End-of-pipe integration is not equipped for addressing lack of knowledge about how aspects are interrelated and for considering conflicts between various groups about how they perceive a particular problem in the real-world, their values, and their daily practices.
- How do insights of TR typically gained in case-study research differ from insights gained in standard research? The design of standard research facilitates generalizing results. In contrast, TR conducts research on cases to provide knowledge that will be effectively used in the particular case under investigation. What can be learned for another case requires observing outcomes with a view to supporting and restricting factors for effective use (Hirsch Hadorn et al. 2002; see also Krohn, this volume). Those factors may then serve as conditions for transferability, which need to be checked for every target case. This step is important to avoid reinventing the wheel for every case as well as suggesting unjustified generalizations.
- How does evaluation of TR differ from evaluating disciplinary excellence plus the added value? As integration in TR has to deal with diverse challenges, different forms and methodological approaches to integration have been developed. Integration being a core quality of inter- and transdisciplinary research, these methods and results need to be assessed using appropriate criteria for the respective types of integration (see Huutoniemi and Rafols, this volume). Furthermore, the most effective means for evaluating societal impacts is still an open question.

These questions point out the need to elaborate on concepts, approaches, and methods of TR. In addition there are further institutional and educational questions as well as the question whether or not there should be a specialized community of TR peers (Bammer 2013).

23.7 An Example of Addressing Problems in Transdisciplinary Research: Sustainability Foresight for Utility Sectors

Foresight processes can be interpreted as instances for transdisciplinary knowledge production. Utility sectors are particularly interesting in this regard. They are currently experiencing accelerated and fundamental changes, which open up spaces for sustainable reconfigurations. The Sustainability Foresight project was mandated by the German ministry for education and research (bmb + f) within the transdisciplinary socioecological research program (www.sozial-oekologische-forschung.org). The project aimed at developing sustainable development alternatives for German utility sectors within a time frame of 25 to 30 years (Truffer et al. 2008). It was run by an interdisciplinary research team of German and Swiss researchers between 2002 and 2006 (www.mikrosysteme.org). The project focused on the electricity, gas, water, sanitation, and telecom sectors. It asked whether the historical paradigm of utilities as public service could give way to a new overarching sustainability paradigm, or whether each sector was more likely to develop according to its own specific logic. Finally, the project was intended to provide strategies for promoting system transformations toward new, more sustainable forms of utility services. Sustainability Foresight puts emphasis on sectoral production and consumption systems as coherent configurations of institutions, technologies, cultural and environmental structures. Moreover, it encompasses an elaborated assessment and strategy phase after the initial scenario construction.

The Sustainability Foresight method was based as a broad stakeholder process in which utility firms, technology developers, environmental and consumer NGOs, government officials, and researchers all elaborated on their expectations. This broad setting was chosen because each actor group may contribute to the overall analysis based on his or her own rationality and in accordance with its specific knowledge. This knowledge may relate to the structure and potential future dynamics of the sector (system knowledge); to goals which a sector should try to fulfill, as well as trade-offs that might exist when trying to reach specific goals (target knowledge); and finally to the knowledge about potential actions that might support a transformation (transformation knowledge). As a consequence, expectations are likely to differ not only on their substance but also with regard to the access to supporting evidence and even with regard to wording and framing.

The Sustainability Foresight procedure was structured into three phases:

- Exploration of expected transformation dynamics: It consisted of an analysis of implicit visions about the future of the selected utility sectors. Each analysis was brought to a conclusion by an expert workshop with key representatives of different actor groups. Based on perceived development trends, four overarching scenarios were constructed in three participatory scenario workshops. In the scenario workshops, critical innovation fields were identified whose success would be necessary for certain scenarios to become true.
- Sustainability assessment: The four scenarios were characterized with regard to their challenges and opportunities related to sustainability criteria. The evaluation criteria were determined by scientific experts from different fields of competence. Preferences were elicited in a stakeholder workshop. Stakeholders were carefully selected in order to represent the whole range of different value positions.
- Derivation of transformation strategies: Based on the four sector scenarios and the risks and opportunities derived from the sustainability assessment, potential development trajectories for three critical innovation fields were worked out by the project team. Roadmaps for development were then presented in a final workshop to representatives of the utility sectors and experts for the selected technologies in order to derive potential coordinated strategies that could lead to more sustainable utility structures in the long run.

Each of the three project phases ran over 1 year and involved a broad range of stakeholders, who were invited in order to respect a predefined quota that would guarantee a broad and balanced spectrum of knowledge types and perspectives. The core analytical steps were carried out conjointly between project team and participants. Overall, about 150 experts were participating in one way or another in the project. Among these, about 120 stakeholders participated in the 9 workshops. Each workshop ran over 2 days and encompassed roughly 20 participants. The process allowed the translation from implicitly held visions on sustainable future utility sectors into a potentially more widely shared transition agenda. Carrying out this procedure as a participatory process was necessary because, in general, no shared understanding of the system dynamics existed and a high number of potential and actual conflict lines could intervene in any attempt to directly formulate sustainability strategies for these sectors. The process yielded an elaborate set of arguments for coordinating the different individual strategies, which could lead to formulating joint innovation projects.

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Managing Consensus in Inter- and Transdisciplinary Teams: Tasks and Expertise

RICO DEFILA AND ANTONIETTA DI GIULIO

1 Collaborative Problem Framing and Consensus

One of the most important requirements of inter- and trans-disciplinary research consists in what we call "consensus": By means of suitable procedures and methods, participants have to arrive at a shared view of a problem and how to deal with it. Consensus here doesn't mean "agreement" in an everyday sense. Neither does it mean identification of the least common denominator. Rather, it means development of models and theories that integrate various disciplinary viewpoints in such a way that the result is shared by all. Sharing the description of the object of research does not mean that participating researchers develop an identical perspective on the issue to be investigated, replacing their individual ones. Rather, it means, first, that the common description is agreed on because all participants are convinced it makes sense, encompasses what they think to be relevant, is coherent and consistent to them, does not contradict their beliefs, and is commensurable to their approaches. Second, that the common description allows for individuals to relate their different research approaches and results to both this description and each other. Third, that all are willing to relate their inquiry and results to the shared description.

Problem framing that incorporates diverse perspectives lies at the heart of successful inter- and transdisciplinary work—success being defined as achieving a synthesis (integrated result) that is more than just the addition of different points of view and single results. Hence, we conceive inter- and transdisciplinarity as an endeavor seeking to integrate knowledge (for a critical discussion of integration, see Holbrook 2013).

Problem framing consists of the following elements (see also Pohl et al., this volume):

- defining the problem (what it is, for whom, the factual background, assumptions, and type of knowledge needed to understand the problem, and context in which it is meaningful)
- figuring out possible solutions (what is causing the problem, how it can and should be approached, where the most promising solutions could be found)
- identifying resources needed to solve the problem (e.g., money, time, perspectives and methods, certified and non-certified experts)

Problem framing in inter- and transdisciplinary teams is collaborative problem framing. In the case of wildland fire, for example, Brooks et al. (2006) state that "Problem framing involves the different ways that stakeholders define the problem and the terminology and concepts related to it. . . . Different frames allow stakeholders to see what they want to see, or what they are guided to see. . . . The existence of many different frames, or definitions of the problem, suggests a need to develop common goals and a common language" (ibid. 2006, p. 3).

A broad body of research and literature reinforces Brooks et al.'s explanation, as do the results of a survey conducted by the DACH project. In 1999 we sent researchers from four inter- and transdisciplinary environmental research programs in the countries of Germany (D), Austria (A), and Switzerland (CH) a written questionnaire on research management, leadership and personal skills, methods of knowledge integration, development of shared theories, team development, and so

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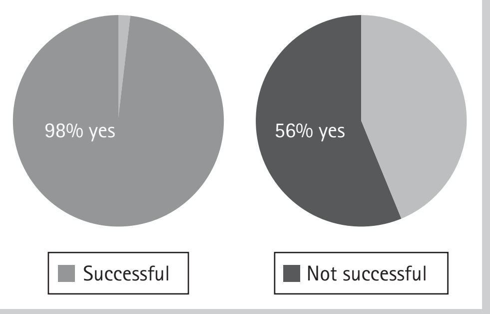

FIGURE 23.3 Common goals. Of those who achieved a synthesis, 98% said that they had had common goals, whereas only 56% of those who had not achieved a synthesis had common goals (Defila et al. 2006, p. 72).

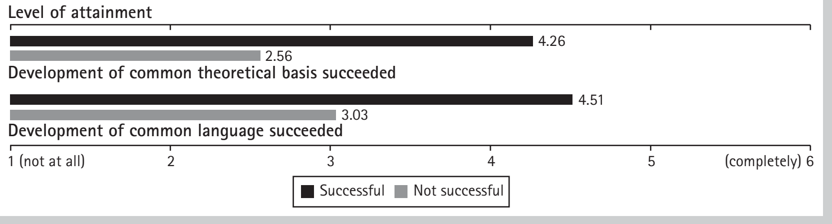

FIGURE 23.4 Common language, common theoretical basis. Those having achieved a synthesis (the successful ones) were also successful concerning development of a common language and theoretical basis (Defila et al. 2006, p. 118).

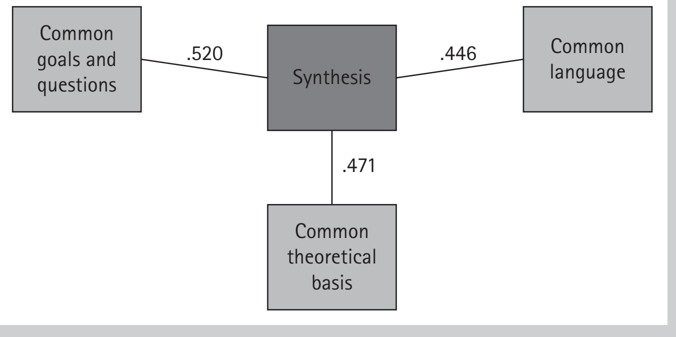

FIGURE 23.5 Success factors. Correlation between common goals and achieved synthesis is rather high, as are correlations between common language and synthesis and between a common theoretical basis and synthesis (Defila et al. 2006, p. 49).

forth (asking about their experiences and recommendations). We received 294 completed questionnaires out of a possible 649, a return rate of 45%. The results clearly show significant differences concerning common goals, language, and theoretical basis between those who had achieved a synthesis and those who had not (Figures 23.3, 23.4, 23.5).

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Managing Consensus in Inter- and Transdisciplinary Teams (cont.)

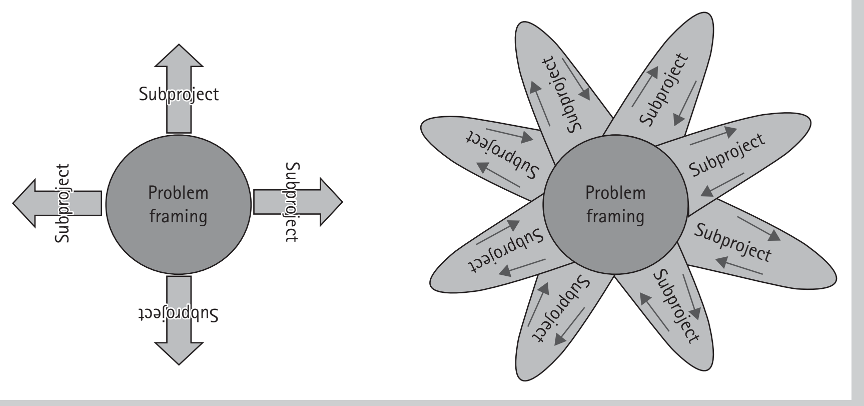

FIGURE 23.6 Balancing teamwork and individual work. Put metaphorically, the division of labor and collaborative problem framing together resemble a flower, the petals standing for the individual research work respectively the research work in subprojects.

Not every step in an inter- and transdisciplinary research project can be carried out collectively. Yet common goals, questions, and a shared description of the research object are the starting point for inquiries of individuals and/or subprojects and the point to return to after their results are available. As a result, balancing collaborative and individual work is a crucial part of managing research projects (Figure 23.6).

2 Fostering Consensus

Many projects fail at collaborative problem framing, and, consequently, in developing integrated results, for two reasons. First, they often have a deficit of theory and methodology with regard to inter- and transdisciplinary processes. Second, disciplinary socialization reinforces the segmentation of disciplinary worldviews (see, e.g., Di Giulio 2010; O'Rourke & Crowley 2013). Interdisciplinarity does not dispose of disciplinarity, ignoring or covering up differences. On the contrary, to be successful, members of a team have to make substantial contributions based on their disciplinary ways of thinking and of investigation. To this end, they need a strong disciplinary identity and deep understanding of their specialized ways of thinking and tackling scientific problems. Disciplinary perspectives will not be productive for interdisciplinary research, if team members are not able to relate their way of problem framing to that of others. If all are convinced that their own worldviews, questions, and methods are the only right ones for success, a collaborative problem framing is beyond reach. A strong disciplinary identity is both the sine qua non of success and a serious obstacle in interdisciplinary research. Therefore, disciplinary problem framing and collaborative problem framing have to be balanced. Otherwise, collaborative problem framing in interdisciplinary teams and a productive balance of teamwork and individual (disciplinary) work will not just happen, even if all team members are strongly committed.

Two questions then follow. Which processes have to be managed in order to establish successful interdisciplinary work from the beginning? And, what kind of expertise is needed from those in charge of managing these processes?

3 Processes Needing Management

Teams often concentrate only on the process of integration, and approach the task at the end of the project. This approach is dangerous. Close attention must be paid to the process of collaborative problem framing, including defining common goals and questions (see also, e.g., Lefroy 2013). Hence the beginning is as important as what follows. Postponing integration-oriented work to the very end will increase the chance of ending up with either the least common denominator or an unrelated list of results. Achieving integrated results entails some kind of collaborative problem framing at the very beginning of a project, though it does not have to be completed at that stage. Rather, collaborative description of the research object as well as the definition (and reprocessing) of common goals and questions should start even before a project begins and then will accompany a project until its completion (for a discussion of the nonlinearity of such tasks, see Holbrook 2013). They are not isolated tasks in the life span of a project but are crucial running tasks of managing interdisciplinary (and transdisciplinary) projects.

In addition, six other tasks require attention (see Defila et al. 2006):

- coordinating the research of participating individuals and/or subprojects, supporting joint surveys and other joint research activities;
- designing development of integrated results by choosing appropriate methods, implementing these methods, ensuring development of common results (synthesis), and ensuring the research ends up with common products;
- supporting team development by discussing expectations of team members toward each other and the project, by monitoring team process with special attention to possible conflicts due to disciplinary socialization;
- supporting participation of (future) users (or "practitioners" or "non-certified experts") and cooperation between researchers and users by negotiating goals and forms of cooperation, by reaching agreement on the contribution of the users in terms of time and effort as well as products, and by ensuring they benefit from the cooperation;
- designing and monitoring internal and external communication by defining the different academic and nonacademic target audiences to be addressed, defining the different ways and languages needed for addressing target audiences, and discussing respective assignments concerning communication within the project team;
- and finally, organizing work within the project team by negotiating rights and duties, discussing criteria to be used in evaluating the processes and achieved results, and aligning the different disciplinary work schedules.

For more details on integration and reasons not to call non-certified experts "stakeholders," see Defila and Di Giulio (2015).

The processes related to these tasks do not just happen. Those in charge of managing a project initiate and moderate them, ensuring involvement and active participation of everyone being part of the project, and at the same time they themselves participate in integration by making contributions. We call this a "content-rich moderation" ("inhaltsreiche Moderation": Defila et al. 2006, p. 126; Defila & Di Giulio 2015). Such moderation should be scientifically sound, encompass both social and cognitive aspects, take into account the academic disciplines and professional fields of team members, and occur in a way that suits the topic, goals, and questions of the research.

(*cont.*)

Managing Consensus in Inter- and Transdisciplinary Teams (cont.)

Management of inter- and transdisciplinary research cannot be reduced to simple technicalities. It is a complex scientific task requiring special expertise.

4 Expertise for Managers of Inter- and Transdisciplinary Projects

To help achieve integrated results and to perform a "content-rich moderation" the following kind of expertise is required by managers:

They must know how to encourage lasting communication and help break down boundaries of communication (see, e.g., Lefroy 2013). They have to recognize controversies caused by different disciplinary worldviews and distinguish them from those caused by dissenting opinions. They have to foster mutual understanding (e.g., by applying appropriate tools such as those O'Rourke & Crowley [2013] describe). They have to make sure collaboration is accompanied by careful reflection on the disciplinary ways of structuring the world and disciplinary contributions to solving the problem at hand.

They have to identify potential contributions to common questions originating from different approaches represented on the team, although participating researchers may not notice them, and they have to discuss this potential so it makes sense to everyone. And they have to recognize links and patterns across disciplines.

They have to know appropriate and state-of-the-art methods to initiate collaborative problem framing and integration of results for one thing, and they must be able to choose and implement state-of-the-art approaches while tailoring them to the immediate project for another thing. To do so they need technical knowledge and scientific creativity with regard to the design of inter- and transdisciplinary processes.

In addition, throughout the research work, they have to make sure research is informed by common goals and questions and actually refers to the common description of the research object. They must also be able to distinguish whether someone (or a subproject) is moving away from the common ground and needs to be brought back, or whether the common ground needs to be reprocessed. Doing so requires technical expertise with regard to the topic being investigated.

Collins and Evans provide a useful framework for defining the expertise needed. They distinguish "contributory expertise" from "interactional expertise" (2002, p. 254). The first means enough expertise to contribute to a specific academic field, and the second enough expertise to interact interestingly with those belonging to a specific field. In talking about "managers and leaders of large scientific projects" they explain, "to manage a scientific project at a technical level requires, not contributory expertise in the sciences in question, but experience of contributory expertise in some related science . . . the managers must know, from their own experience, what it is to have contributory expertise" (i.e., "referred contributory expertise"). Additionally, managers should not only have "interactional expertise" but also the "ability to translate," and the "ability to discriminate" with regard to the sciences involved in a project (p. 257f.). Moreover, what Collins and Evans do not mention, managers should have at least interactional expertise with regard to those doing research on inter- and transdisciplinarity to ensure that practice is informed by understanding of their theoretical and methodical basics.

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CHAPTER 24

UNDERSTANDING CROSS-DISCIPLINARY TEAM-BASED RESEARCH

Concepts and Conceptual Models from the Science of Team Science

KARA L. HALL, BROOKE A. STIPELMAN, AMANDA L. VOGEL, AND DANIEL STOKOLS

Over the past two decades marked increases in cross-disciplinarity, team-based approaches, and a focus on solving real-world problems have reflected important shifts in the culture of science. There have been significant investments in these approaches during this time by government, academic institutions, and industry alike. These investments have aimed to accelerate scientific discovery and innovation and to make meaningful advances toward solving complex scientific and societal problems. A consensus is growing that by applying conceptual, theoretical, and methodological approaches from multiple disciplines, fields, and professions in an integrated manner, we can accelerate innovation and produce more holistic solutions to complex problems.

The US government has made substantial investments in large collaborative research initiatives such as the Clinical and Translational Science Award (CTSA) program of the National Institutes of Health (NIH), the Cyber-Innovation for Sustainability Science and Engineering (CyberSEES) program of the National Science Foundation (NSF), and NASA's ROSES: Ocean Vector Winds Science Team. Growing federal investments in small science teams has led to the development of supports such as the multiple principal investigator (MPI) mechanism created by the NIH in 2006. The mechanism is now used by approximately 20% of all new R01 grants (Stipelman et al. 2014). The NSF also has seen a steady increase in the number of awards granted to projects with multiple PIs, while the number of single PI awards has remained stable (National Science Foundation 2013).

The science of team science (SciTS) has emerged over the last decade in response to these trends. The field aims to develop an evidence base for what team characteristics and processes, and what institutional, funding, and other conditions promote effective collaboration in science, often with a focus on cross-disciplinary teams. This chapter discusses the history

Hall, K., Stipelman, B. A., Vogel, A. L., and Stokols, D., *Understanding Cross-Disciplinary Team-Based Research: Concepts and Conceptual Models from the Science of Team Science.* In: *The Oxford Handbook of Interdisciplinarity, Second Edition.* Edited by Robert Frodeman, Julie Thompson Klein, and Roberto C. S. Pacheco: Oxford University Press (2017). DOI 10.1093/oxfordhb/9780198733522.013.28

of the SciTS field, highlights key concepts, and reviews several conceptual models that can aid in engaging in, facilitating, supporting, and evaluating cross-disciplinary team-based research.

24.1 What Is Team Science?

Early conceptualizations of team science (TS) focused on large-scale, cross-disciplinary team-based research (Stokols et al. 2008a). Since then, a growing body of knowledge has shown evidence-based practices that apply to large teams also apply to small teams, and that challenges experienced by cross-disciplinary teams also can be experienced by unidisciplinary teams. As a result, TS is generally defined as scientific work conducted interdependently by a team of two or more researchers (National Research Council 2015). It contrasts TS with groups composed of individuals who may share space or infrastructure but otherwise typically operate independently to achieve their scientific goals.

The National Academy of Sciences' report, *Enhancing the Effectiveness of Team Science*, identified seven key dimensions of science teams that influence team processes and outcomes (National Research Council 2015). These are: diversity of membership, degree of knowledge integration, team size, degree of goal alignment, permeability of team boundaries, geographic dispersion of team members, and degree of task interdependence. Team processes and effectiveness also are influenced by a range of intrapersonal, interpersonal, organizational, and external factors (see Figure 24.1). Intrapersonal influences include collaboration readiness and transdisciplinary orientation (Hall et al. 2008; Misra et al. 2015). Interpersonal influences include team processes and team dynamics (Hall et al. 2012). Organizational influences include the number and types of organizations involved in a team; their unique cultures, policies, and procedures; and their available infrastructure and resources to facilitate TS (Vogel et al. 2014). External influences include the disciplines and fields that are represented by members of the science team, and their unique values, epistemologies, and conventions; trends in science policy and funding; and broader societal and technological trends (Adolph et al. 2012; Vogel et al. 2014).

The scientific goals of science teams influence team dimensions and processes. The nature of the problem being researched drives decisions about what disciplines and fields are engaged, and what degree of knowledge integration is needed. These factors in turn influence the composition and size of the team, the degree of task interdependence, and whether or not team members are colocated or geographically dispersed, factors that then influence team processes. For example, teams that are highly cross-disciplinary will benefit from processes that externalize group cognition, so they can ensure that members share a common understanding of the research problem and clarify the contributions of each participating discipline (Fiore et al. 2010; Hall et al. 2012). Translational research teams that include community stakeholders can benefit from applying methods for coproduction of knowledge (e.g., About td-net's toolbox 2015; Pohl et al. 2008). Finally, scientific goals may require such significant scientific infrastructure (e.g., Human Genome Research Project and Large Hadron Collider) that the team composition and processes are shaped by multiple government agencies and universities, each of which introduces its own procedures, policies, resources, and culture.

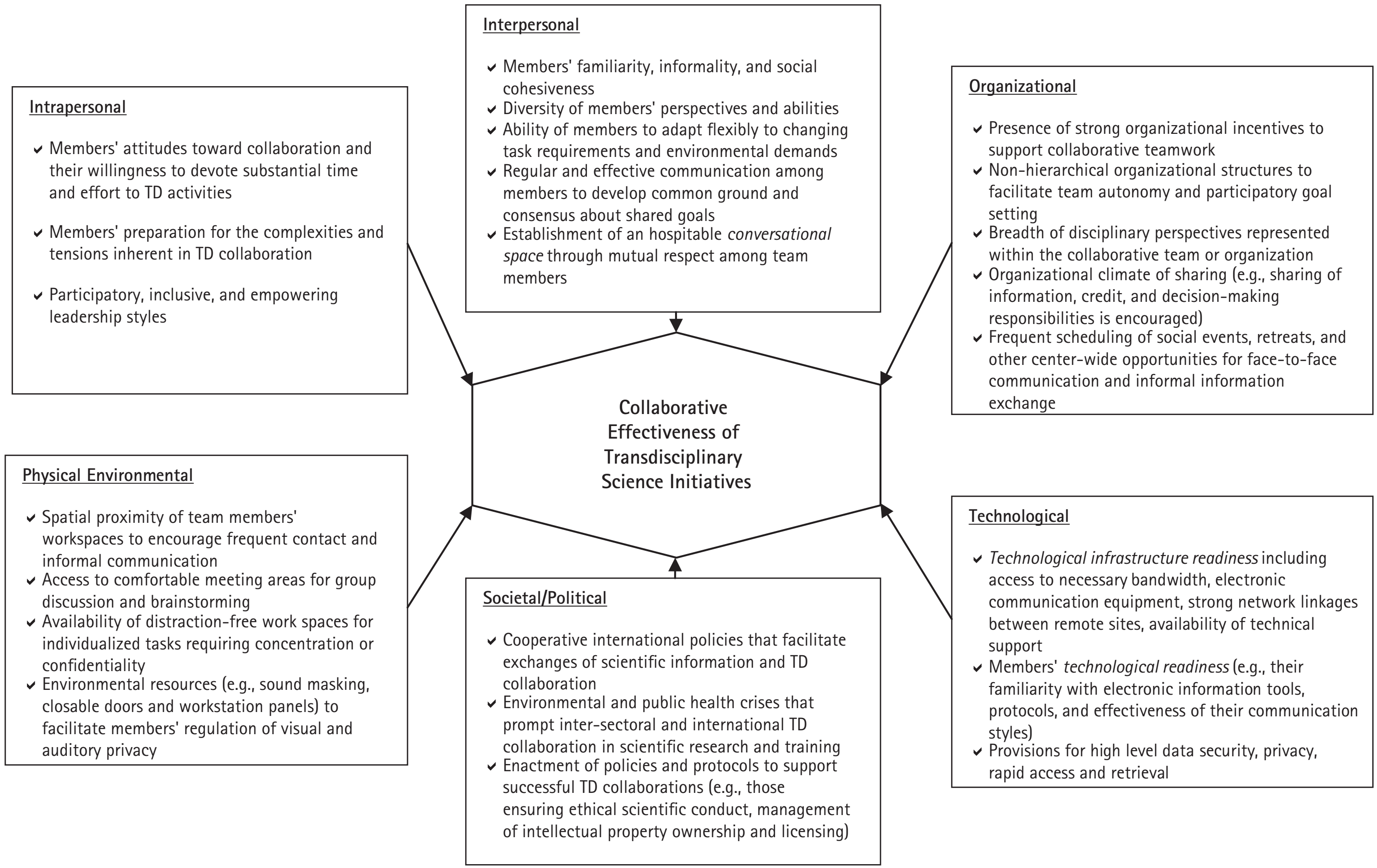

FIGURE 24.1 Typology of contextual factors influencing transdisciplinary scientific collaboration.

Reprinted from Stokols et al., 2008 with permission from Elsevier.

The range of potential team dimensions and scientific goals results in a wide array of possible profiles of science teams, all of which are considered "team science." For instance, science teams can range from a pair of scientists from the same discipline working together at a single site to hundreds of researchers from a broad range of disciplines working collaboratively across time zones, cultures, and organizations. Each profile introduces unique strengths and challenges, meaning there is no "one-size fits all" approach to success in TS, but a variety of evidence-based practices to select from.

24.2 Defining Cross-Disciplinary Research

Teams vary in the degree of integration among contributing disciplines, as needed to address the research problem, with "discipline" defined broadly to also include fields, domains, professions, and community and policy arenas. Disciplinary integration involves integration of concepts, theories, approaches, and methods, and occurs along a continuum, with unidisciplinary research on one end and transdisciplinary research on the other (Figure 24.2; c.f., Rosenfield 1992; Stokols et al. 2008a). We define unidisciplinary (UD) TS as any endeavor in which two or more researchers, all sharing the same disciplinary perspective, work interdependently to address a scientific problem. We identify three types of cross-disciplinary integration: multidisciplinary (MD), interdisciplinary (ID), and transdisciplinary (TD) (see also Klein, this volume). *Multidisciplinary TS* occurs when two or more researchers from different disciplines work sequentially to address a scientific problem, each staying rooted in his or her own discipline-specific perspective, with the goal of addressing the scientific problem from each perspective. *Interdisciplinary TS* aims for a higher degree of cross-disciplinary integration, with team members from different disciplinary backgrounds working

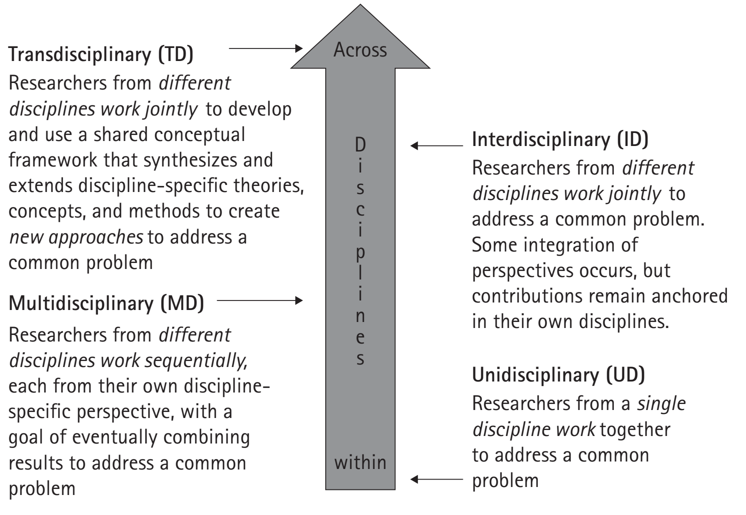

FIGURE 24.2 Continuum of disciplinary integration.

National Research Council 2015.

interdependently to integrate perspectives, concepts, and methods to some degree, but contributions remain anchored in their originating disciplines. *Transdisciplinary TS* represents the greatest degree of cross-disciplinary integration. Researchers from different disciplines work interdependently to develop and apply conceptual frameworks, theories, methods, and measures that both *synthesize and extend beyond* discipline-specific approaches to create new approaches to address the scientific problem.

24.3 The SciTS Field: Origins, Goals, and History

Although some scholarship related to TS and interdisciplinarity was produced from the mid- to late 1900s (e.g., Pelz 1967; Pelz & Andrews 1966; Payne 1990), scholarship in this area accelerated in the early 2000s in response to heightened attention to and growing investments in TS (National Research Council 2003; National Academy of Sciences 2005). This scholarship highlighted the growing sense that TS not only had the potential to catalyze innovation in science and better address real-world problems but also introduced unique challenges that must be understood and managed in order to maximize the effectiveness of science teams. In 2006, this area of scholarship became known as the SciTS field (pronounced "sights"). The science of team science is a cross-disciplinary field of study that aims to build an evidence base for effective practices in TS, and to develop practical resources (e.g., guidelines, trainings, model policies) to help investigators, institutions, and funders apply these evidence-based practices with the ultimate goal of enhancing the science produced by teams.

The science of team science is a subfield of science studies (Hess 1997). Grounded in a wide range of disciplines, fields, and communities of practice, SciTS contributors include, but are not limited to, science studies, communications, management science, psychology, cognitive science, public health, information science, library science, community-based participatory research, citizen science, and patient-centered research.

Key efforts over the past decade propelled the growth of the SciTS field (Figure 24.3). A number of early coalescing events in the SciTS field occurred from 2005 to 2008. Building on the National Academy of Sciences report, "Facilitating Interdisciplinary Research" (2005), in 2006 the NIH and the American Psychological Association (APA) supported the conference, "The Science of Team Science: Assessing the Value of Transdisciplinary Research." The conference brought together experts in TS to present an overview of the research about TD TS and identify priority areas and future directions for the SciTS field. The 2006 conference led to the first journal special issue on TS, a 2008 supplement to the *American Journal of Preventive Medicine* (Stokols et al. 2008b), which provided an overview of key research and conceptual developments and future directions in the emerging SciTS field. A subsequent NSF workshop titled "Applying the Science of Teams to Inform Policy and Research on Team Science" (Fiore 2010), provided a forum to apply the science of groups and teams to discussions of the team-based processes required to stimulate innovative cross-disciplinary approaches and address highly complex scientific problems. Together, these events reflected increased federal attention to understanding collaboration and cross-disciplinarity in science. Engagement from participants in the broader scientific community demonstrated high demand for SciTS scholarship.

The SciTS field continued to grow as a community with the Annual International SciTS Conference established in 2010 (www.scienceofteamscience.org). It has brought together thought leaders in the SciTS field—including emerging SciTS scholars, investigators who use TS approaches, institutional leaders who promote TS, and policy makers and funders interested in supporting TS—to share the latest SciTS scholarship and evidence-based principles for success in TS. Two additional journal special issues, including a special issue of *Translational Behavioral Medicine* (Spring et al. 2012), titled "Team Approaches to Science, Practice and Policy in Health," and a special issue of the *Journal of Translational Medicine and Epidemiology* (Lotrecchiano 2014), titled "Collaboration Science and Translational Medicine," also showcased ongoing empirical and conceptual work in the SciTS field.

An important milestone for SciTS was the release of the National Academy of Science report "Enhancing the Effectiveness of Team Science," in 2015 (National Research Council). Based on a comprehensive consensus study by a committee of leading national scholars, the report reviewed the current state of knowledge in the SciTS field and recommended ways to enhance the effectiveness of collaborative research in science teams, research centers, and institutes. The report, downloaded more than 17,000 times in the first year and identified as among the top three most downloaded NAS reports in 2015, highlighted the increasing demand by the scientific community for evidence-based principles for how to support, manage, and conduct TS.

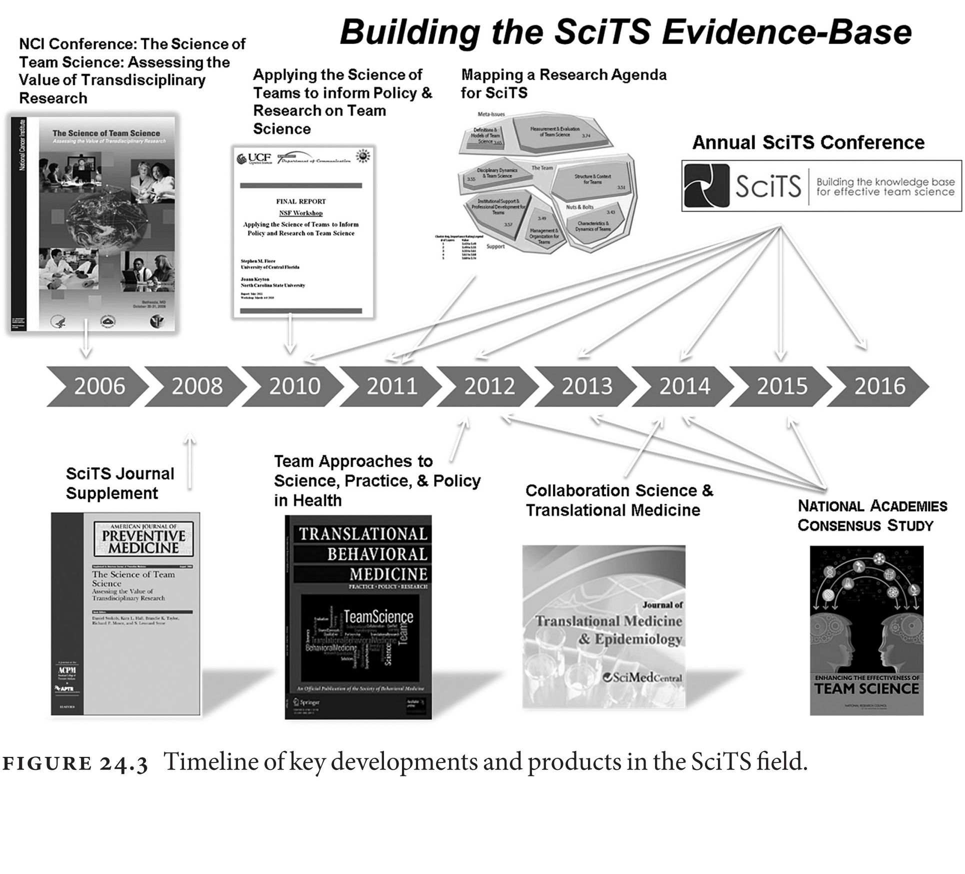

FIGURE 24.3 Timeline of key developments and products in the SciTS field.

24.4 Advancing the SciTS Field and Enhancing Cross-Disciplinary Collaboration Through Conceptual and Theoretical Models

Enhancing the effectiveness of cross-disciplinary collaboration requires the development of robust evidence of effective approaches. Conceptual and theoretical models serve as the scaffolding for integrating existing and emerging knowledge about effective practices. Models can help researchers to more explicitly codify, test, and refine knowledge, and identify gap areas. These models can also help in the application of evidence-based practices to real-world teams. In this portion of the chapter, we highlight theoretical and conceptual models with relevance to advancing SciTS knowledge and enhancing team science in practice. First, we highlight models of the SciTS field and the ecology of cross-disciplinary team science that identify priorities to strategically advance programs of SciTS research, and identify multilevel areas for potential interventions to enhance team science in practice. Next, we discuss models of team science influencing factors and processes for effectiveness, to guide science teams in practice, as well as efforts to facilitate and support team science. Lastly, we review a number of evaluation models emphasizing the opportunity to learn from existing team science programs and enhance their functioning, management, and support.

24.4.1 Models of the SciTS Field and Cross-Disciplinary Team Science

As the SciTS field has matured over the past decade, there have been efforts to provide a framework to better define the scope of the SciTS field and highlight important areas for future inquiry (Börner et al. 2010; Falk-Krzesinski et al. 2010, 2011). In addition, models have been created to highlight key factors that influence TS from a social-ecological and systems perspective (Stokols et al. 2008c; Huang 2015). Here we highlight several examples.

24.4.1.1 Concept Map for the SciTS Field

In conjunction with the First Annual International SciTS Conference in 2010, Trochim and colleagues (Falk-Krzesinski et al. 2011) used a concept-mapping approach to engage the emerging SciTS community in creating a comprehensive taxonomy of TS that could also serve as a framework for a SciTS research agenda (Figure 24.4). The resulting concept map consisted of eight thematic clusters, each representing a distinct area of scholarly interest and activity in the SciTS field: Definitions and Models of TS; Measurement and Evaluation of TS; Disciplinary Dynamics and TS; Structure and Context for Teams; Institutional Support and Professional Development for Teams; Management and Organization for Teams; and Characteristics and Dynamics of Teams. This concept map has served as a roadmap for

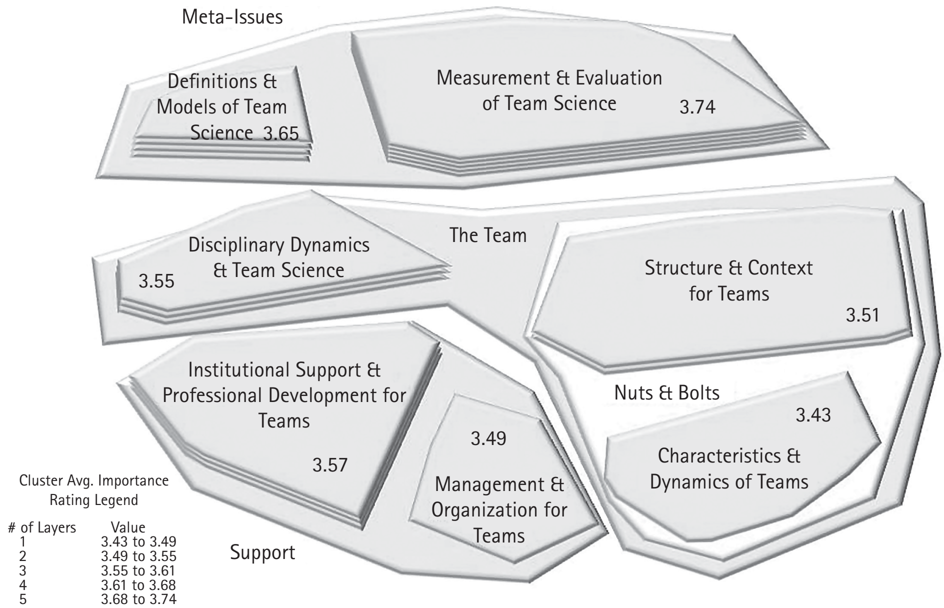

FIGURE 24.4 Science of team science concept map.

Reprinted from Falk-Krzesinski et al., 2011 with permission from Oxford University Press.

moving the SciTS field forward by highlighting important theoretical, empirical, and translational areas for future scientific inquiry, funding, and policy. A content analysis of accepted abstracts for the 2014 SciTS conference found that each area on the map was represented, with Measurement and Evaluation—a large area of the 2011 map—being most common (36% of abstracts) and Characteristics of Team Dynamics and Management and Organization for Teams—smaller areas of the 2011 map—being the least common (5% and 6% of abstracts, respectively) (Fiore 2014).

24.4.1.2 Ecology of Transdisciplinary Team Science

Stokols and colleagues (2008c) developed an ecological model for TD TS that identified multilevel influences on successful TS, helping to illuminate the contextual determinants of collaboration success (Figure 24.1). The model was designed to be useful to a variety of stakeholders, by providing an understanding of the wide variety of factors that can be intervened on to enhance the success of TS.

This conceptual model was generated from one of the first systematic reviews of teamwork and team effectiveness conducted in the SciTS field. Stokols et al. 2008 reviewed the empirical literature on team performance and collaboration from four distinct areas of research: (1) social, psychological, and management research on the effectiveness of teams in organizational and institutional settings; (2) studies of cyberinfrastructure used to support TD scientific collaborations; (3) field investigations of community-based coalitions for disease prevention and health promotion; and (4) studies that focus specifically on the antecedents, processes, and outcomes of effective collaborations within TD research centers and training programs. The model includes six categories of factors that influence the processes and outcomes of TD TS: intrapersonal, interpersonal, organizational, physical environmental, societal/political, and technological. The variables included within each category have been found to influence the effectiveness of collaboration within scientific and nonscientific teams.

24.4.1.3 Team Science Systems Map

As the empirical SciTS literature grows, there is a need for more sophisticated frameworks that can capture the growing knowledge base about the interdependent multilevel factors influencing TS. A systems mapping approach can provide a holistic visual depiction of these factors and their interrelationships (Huang et al. 2015). The NCI SciTS team has been leading a multiphased effort to develop a systems map of TS. While many systems maps rely exclusively on expert opinion to generate their content, the SciTS team is using a hybrid approach that combines factors and relationships established in the research literature along with expert review. In the first phase of the project, the SciTS team screened over 4,000 articles and ultimately coded 50 quantitative empirical articles. From this process, the team identified four main content domains (individual, team, institutional/organizational, policy/societal) along with over 300 constructs and over 500 relationships (Huang et al. 2015). The team intends ultimately to generate an interactive Web-based map of the SciTS field that will allow users to zoom into areas of the map that are of particular interest and explore these areas with greater depth and granularity. The finished map can be leveraged by stakeholders in TS to ensure that they are adequately addressing key factors that may influence the success of their teams. It can also be used to identify critical gaps in the research literature, select appropriate research targets that build on existing knowledge, and encourage more complex research designs.

24.4.2 Models of Influencing Factors and Processes for Effectiveness

Other TS models focus in on understanding the team research process including the interpersonal and social processes that influence success in TS.

24.4.2.1 Four Phase Model of Transdisciplinary Team Science

Hall and colleagues (2012) developed this model to highlight the interacting scientific goals and team processes involved in the life cycle of a TD TS project (cf. O'Rourke, this volume). The model identifies four distinct phases: *development, conceptualization, implementation*, and *translation* (Figure 24.5). Although these phases are presented sequentially, the collaborative process is also recognized as recursive, with movement among the phases as the research collaboration unfolds, such that team members may return to prior phases as needed to address unfolding research questions.

Each of the four phases includes key scientific goals and a set of skills and team processes necessary to maximize the efficiency and effectiveness of a cross-disciplinary team at that

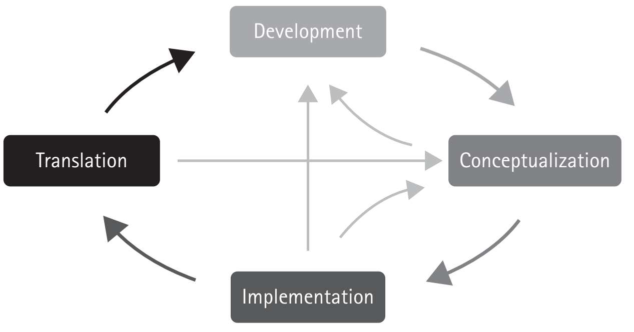

FIGURE 24.5 The four-phase model of transdisciplinary research.
Reprinted from Hall et al., 2012 with permission of Springer.

phase. The *development phase* involves convening a group of potential collaborators to define the scientific or societal problem space of interest. In this phase, critical team processes encourage information sharing and integrative knowledge creation among diverse participants. In the *conceptualization phase*, team members work together to formulate novel research questions, create a conceptual framework, and develop a research design that reflects the integrative nature of the project. Team processes that focus on developing shared language, mental models, and transactive memory (e.g., knowing which team members have which expertise) are vital to help team members move engage in integrative science. The *implementation phase* involves the execution of the planned research project. Key processes around task work, team learning, and conflict management are vital to ensuring success in this phase. Finally, in the *translation phase*, findings from one level of analysis are applied to another in an effort to advance scientific progress along the discovery-development-delivery continuum. Planning for this phase typically begins in the development and conceptualization phases, as the team anticipates translational applications. Key processes from the development and conceptualization phases are repeated as new translational partners join the team.

The four phase model can be used by investigators and translational partners as a roadmap to guide effective cross-disciplinary collaboration by highlighting key collaborative research processes for each phase. It can also serve as a tool for improvement-oriented evaluation. The model also is relevant to organizational leaders and funding agencies, as it provides insight into the resources that can help facilitate effective processes in cross-disciplinary TS.

24.4.2.2 Integrative Capacity Model

Salazar and colleagues (2012) suggest that performance in cross-disciplinary science teams, as measured by knowledge creation, is directly linked to the team's level of *integrative capacity.* They propose a conceptual model of the factors influencing integrative capacity, and the processes by which integrative capacity is achieved (Figure 24.6). They define integrative capacity as the ability to "work across disciplinary, professional, and organizational divides to generate new knowledge . . . through the continuous interplay of social, psychological, and cognitive processes within a team" (2012). Salazar and colleagues posit that integrative capacity can help a team overcome challenges to knowledge integration including a strong

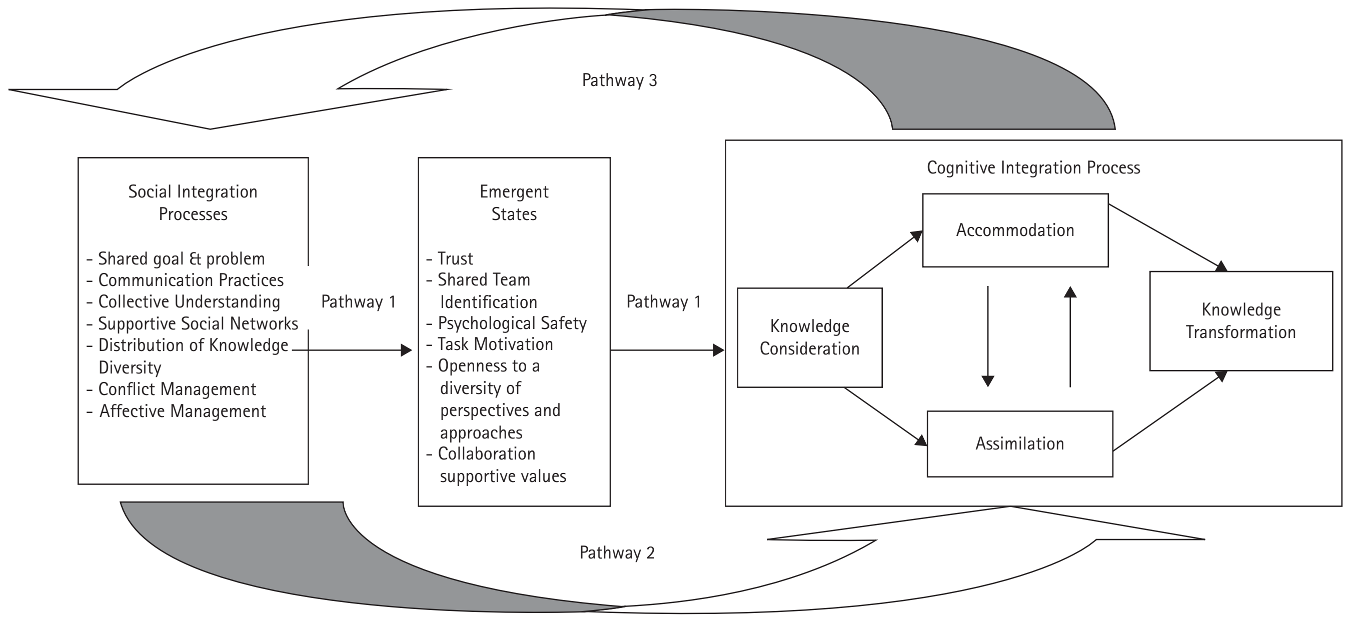

FIGURE 24.6 Integrative capacity.

Reprinted from Salazar et al., 2012 with permission from SAGE.

identification with one's discipline, divergent views of team goals and the problem space, status and power differences among team members, limitations in team members' breadth of knowledge, geographic distance among team members, and too much or too little familiarity among team members.

Salazar and colleagues identify three pathways that compose a team's integrative capacity. In the first pathway, social integration processes on a team (e.g., using effective practices for communication and conflict resolution) facilitate emergent states (e.g., trust, openness to a diversity of approaches and perspectives) that support cognitive integration. Cognitive integration includes knowledge consideration (i.e., the extent to which team members thoughtfully process the knowledge contribution of other team members), assimilation (i.e., the process of assimilating this new knowledge into one's own thinking), and accommodation (i.e., developing new ways of thinking as a result of the new knowledge) to achieve knowledge transformation. In the second pathway, social integration processes directly influence cognitive integration. In the third pathway, cognitive integration influences social integration pathways, as continuous collaboration provides opportunities to regularly improve on and refine the social and cognitive integration processes that enhance integrative capacity.

This model and the integrative capacity construct have important implications for cross-disciplinary TS. Researchers initiating a cross-disciplinary TS collaboration can use this model to better understand the social processes that facilitate the emergent states and cognitive integration processes that underlie increased integrative capacity. Organizations can use the model to assess whether they have the relevant infrastructure and resources (e.g., technology, training opportunities) in place to enable teams to maximize their integrative capacity. Finally, both stakeholder groups can use the model to identify targets for interventions to enhance integrative capacity, in the service of advancing knowledge creation.

24.4.5 Conceptual Models to Guide Evaluation

A number of conceptual models have been developed to help guide program evaluation efforts for cross-disciplinary TS initiatives. The majority of these take the form of logic models, which provide a visual representation of the key antecedents, processes, and outcomes associated with cross-disciplinary team collaboration. These models can be used to help plan for achievement of key benchmarks, to guide quality improvement efforts, and to plan process and outcome evaluations.

Stokols and colleagues (2005) developed one of the earliest logic models for evaluation of cross-disciplinary TS (Figure 24.7), designed specifically to identify the core influences on TD TS. The model highlights interpersonal, environmental, and organizational antecedents of collaboration. Examples include leadership style, participating scientists' commitment to team research, availability of shared research and meeting space, electronic connectivity among team members, and the extent to which team members have a history of working together (Stokols et al. 2005). Intervening processes in this model include intellectual, interpersonal, and affective experiences and collaborative behaviors. Examples include brainstorming strategies to create and integrate new ideas; cross-disciplinary biases and tensions; and strategies for negotiating and resolving conflicts. The antecedent and process variables specified in the model influence near-term, mid-term, and long-term outcomes of scientific collaboration including the development of new conceptual frameworks, research

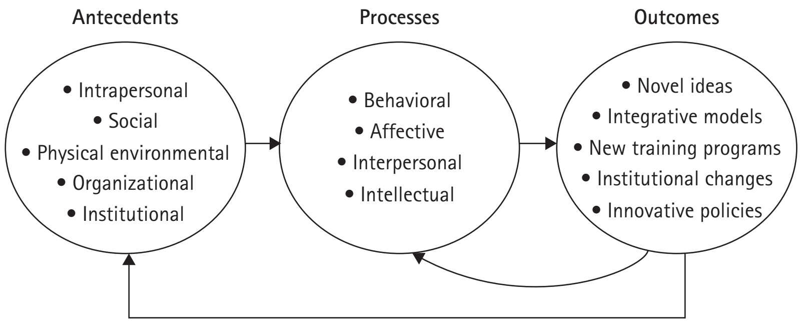

FIGURE 24.7 Antecedents, processes, and outcomes of cross-disciplinary scientific collaboration.

Reprinted from Stokols et al., 2005 with permission from Elsevier.

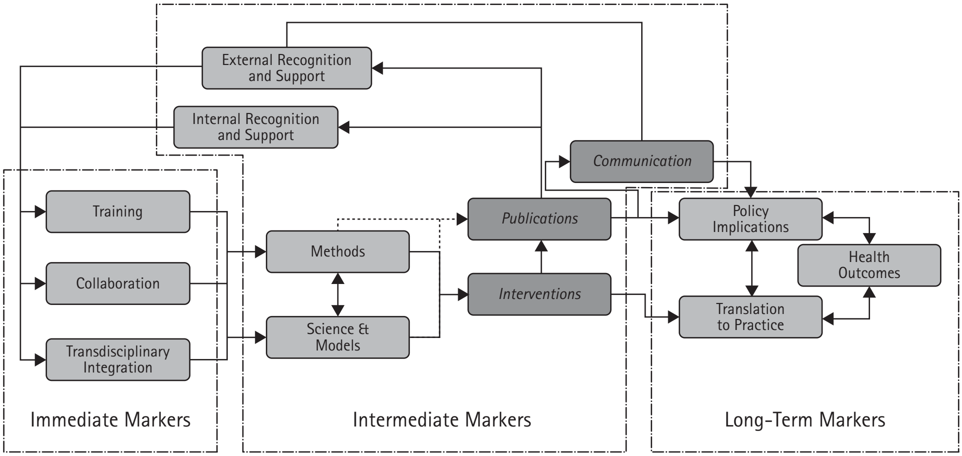

FIGURE 24.8 Logic model for the National Institutes of Health's Transdisciplinary Tobacco Use Research Center (TTURC) Initiative-wide Evaluation Study.

Reprinted from Trochim et al., 2008 with permission from SAGE.

publications, training programs, and translational innovations. Empirical support for the hypothesized links among antecedent, process, and outcome variables was derived from a longitudinal study of the National Institutes of Health's Transdisciplinary Tobacco Use Research Centers (TTURC) initiative (Stokols et al. 2005).

In the context of a more comprehensive evaluation of the TTURC initiative, Trochim and colleagues (2008) engaged stakeholder groups (e.g., TTURC scientists, funding agency officials, scientific consultants) in a concept mapping exercise to identify outcome domains that should be included in the TTURC evaluation. The resulting map was then developed into an outcome logic model that depicted hypothesized sequential causal relationships among the identified outcomes (Figure 24.8). While the Stokols et al. (2005) model highlighted the important influence of antecedents on TS processes and outcomes, the Trochim model (2008) focused on explicating collaborative processes and outcomes and their interrelationships. It posits a series of temporal links between processes of collaboration and TD integration and outcomes including scholarly publications, community health interventions, and public policy initiatives. It highlights constructs of interest for evaluation (e.g., degree of collaboration achieved, emergence of integrative conceptual frameworks) and the sequence in which one would expect to see changes.

Holmes et al. (2008) and Warnecke et al. (2008) developed multistage conceptual models that have guided TD research, training, and community intervention efforts in the Center for Population Health and Health Disparities (CPHHD) initiative of the NIH. From its inception, the CPHHD initiative placed heavy emphasis on community-based participatory research (CBPR) strategies in addition to cross-disciplinary collaboration. Thus, the CPHHD evaluation model incorporates a "community stakeholder—investigator incubator" component (Figure 24.9) not included in previous logic models of cross-disciplinary research.

Misra and colleagues (2009) created a logic model to help guide the assessment of the University of California, Irvine's Interdisciplinary Summer Undergraduate Research Experience (ID-SURE) program (Figure 24.10). This 10-week program provides training on principles of interdisciplinary research coupled with an intensive summer research fellowship. ID-SURE was designed to incorporate the three key components of interdisciplinary training proposed by Nash and colleagues (2003): (1) interdisciplinary coursework; (2) forums for frequent exchange of scholarly ideas among faculty and students; and (3) an institutional climate of openness, respect, and trust that encourages examination of new ideas and experimentation with novel research methodologies. Specifically, the ID-SURE program

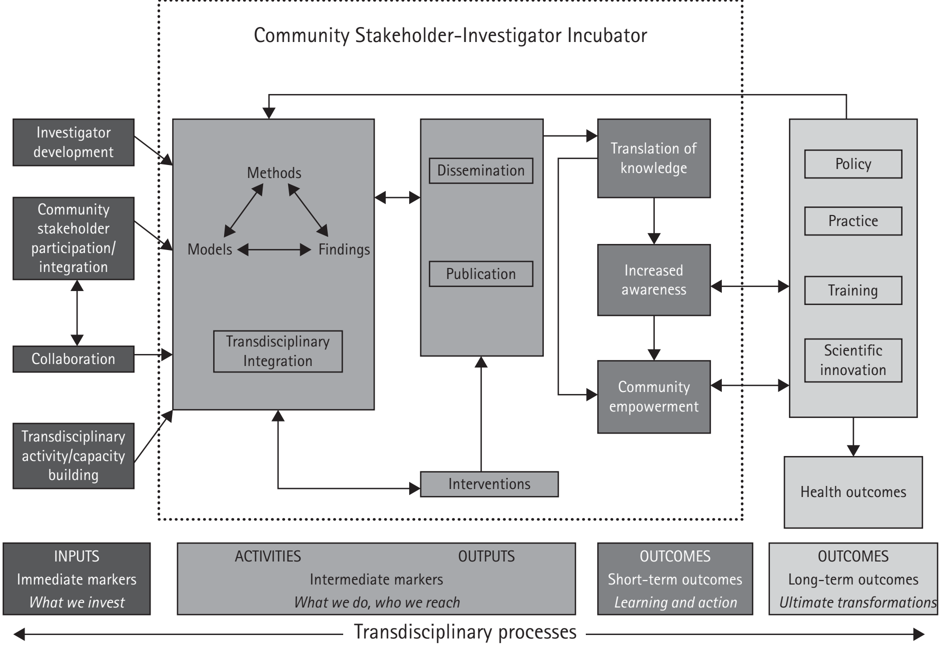

FIGURE 24.9 Logic model for the evaluation of the National Institutes of Health's Centers for Population Health and Health Disparities (CPHHD) Initiative.

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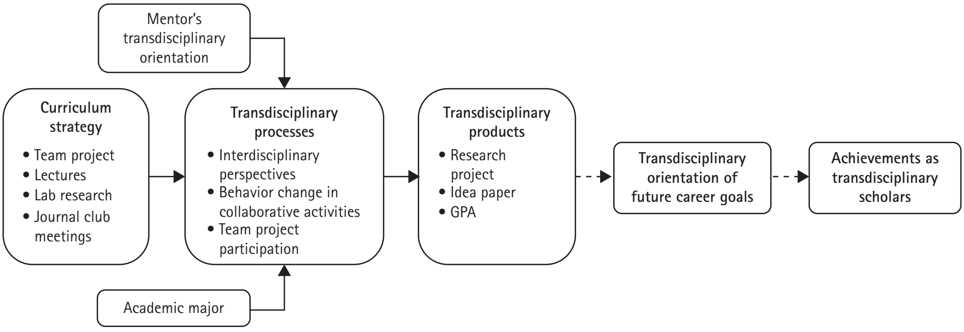

FIGURE 24.10 Logic model identifying ID-SURE Program components and anticipated transdisciplinary influences, processes, products, and outcomes.

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components were a team-taught course offered by a team of faculty at a major university, a collaborative team project where members of each student team were drawn from at least two different academic majors, journal club meetings providing the opportunity for idea exchange, undergraduate research opportunities, and administration by a School of Social Ecology that encourages faculty members and students to integrate disciplinary perspectives in their research. The evaluation logic model highlights the major components of the ID-SURE program and anticipated influencing factors, processes, products, and outcomes.

24.5 Conclusion

Since the launch of SciTS, the field has seen rapid growth in the empirical literature on TS; the development of conceptual models, evaluation approaches, and training resources; and practical tools to enable investigators, academic institutions, funders, and others to implement evidence-based practices for TS. The past decade has also witnessed a steady increase in the number of stakeholders identifying the value of TS and the SciTS knowledge base to advance the scientific enterprise in their disciplines, fields, and settings.

Conceptual models such as those presented in this chapter have helped to (1) identify important areas for advancement of the SciTS field, (2) integrate existing knowledge from the SciTS field and allied fields, (3) build individual programs of research in the SciTS field by identifying important unanswered research questions, and (4) guide development of evidence-based practical tools for enhancing, facilitating, or supporting TS. As the SciTS knowledge base continues to expand, there will be a need to develop new conceptual models that reflect the growing knowledge base. New methodological approaches and technological capabilities can be leveraged for this goal.

There is also the requirement to further develop and refine measures and metrics for TS processes identified in the literature (e.g., externalizing group cognition, managing conflict) in order to build the empirical evidence base about their influence on team effectiveness. There is also a critical need to develop new outcomes measures of TS. Large, complex TS initiatives have complex and numerous outputs and impacts, as illuminated by the evaluation models highlighted above. The heavy reliance on bibliometric analyses in the early stages of the SciTS field to measure return on investments (ROI) in TS—as indicated by number of publications, publication impact factor, and coauthorship networks—reflected a typical analytic approach of funding agencies. But there is a need for additional robust methods to assess the varied and longer-term impact of specific TS initiatives. To capture the breadth of our research goals, evaluation studies should incorporate impacts such as dissemination of ideas, innovativeness, advancement of science, and impacts on society.

It is a formidable challenge to study these outcomes in real-world research contexts. New research platforms, methods, and approaches provide new opportunities to study TS in context. For instance, altmetrics expand options for understanding and tracking a range of research processes and outputs via blog posts, tweets, and other social media interactions. Electronic formats that enable trace data to be captured in real time enable more sophisticated understanding of the temporal scope of translational outcomes of TS initiatives.

It is also important to empirically assess the effectiveness of TS training and educational strategies. For instance, researchers should empirically study the effectiveness of trainings designed to enhance the integrative and collaborative capacity of teams during the various phases of a collaboration. There also is a need to assess the impact of educational programs designed to enhance readiness for cross-disciplinary collaboration.

Finally, as we consider incorporating the SciTS knowledge base to develop translational applications to better conduct, lead, manage, and support cross-disciplinary TS, we need to remain vigilant to the full spectrum of research and academic models that make up our scientific enterprise. This means we need to develop a nuanced approach to TS training and research such that we remain cognizant that not all students and scholars are predisposed toward cross-disciplinary and team-based research. There is a need to develop an understanding of how to combine independent and team activities to maximize innovativeness, rigor, effectiveness, and efficiency. Research that embraces the range of possibilities for independent to collaborative scientific work, and UD to TD work, at all stages of a research endeavor will reflect the reality of how research is conducted today, and will be of the greatest service to enhancing scientific outcomes, our ultimate goal.

We should leave room in our college and graduate training programs for discipline-centric scholarship critical to serving as the building blocks for integration and for those scholars who are not inclined toward TS. Furthermore, not all research questions require a broad-gauged interdisciplinary and TS approach. Therefore, we advocate for the strategic assembly of research teams so that scholars can optimize their particular talents and to be able to recognize and apply them appropriately to the analysis of complex scientific and societal problems when such inquiry requires integrated approaches for their resolution or amelioration.

In sum, this chapter highlights key conceptual models, training models, and evaluation models from the SciTS field that can be immediately useful to considerations of interdisciplinarity in terms of thinking about the team processes underlying interdisciplinary team-based collaborations as well as related evaluation and training efforts. Although still a nascent field, SciTS has contributed much conceptual and empirical work to understanding interdisciplinarity. Also, SciTS holds much promise for continuing to advance our scholarly thinking and to help address pressing scientific and societal problems.

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CHAPTER 25

THE POLICY SCIENCES AS A TRANSDISCIPLINARY APPROACH FOR POLICY STUDIES

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25.1 Introduction

In response to decision maker calls for a "markedly higher standard of information upon which to base their policies and programs" (DeLeon 1997, p. 45), in the early to middle part of the last century scholars began to formalize the field of policy studies. Within policy studies, there exists substantial debate around the content and boundaries of the field. This debate is partially linked to the nature of public policy itself as well as the questions or concepts that the field draws from. A partial list includes effectiveness, justice, power, needs, human nature, public sector, private sector, representation, authority, legitimacy, what governments do, what private organizations do, how agendas are set, and how decisions are made (Theodoulou 2013).

Rather than achieving consensus on any one definition, the field of policy studies continues to expand. However, the one aspect on which all definitions of policy studies and public policy agree is that it is intimately entangled with individuals' daily lives. Generally speaking, policy studies can draw from a variety of disciplinary approaches including, but not limited to, political science, psychology, sociology, and economics to provide insight into policy problems. The degree to which various frameworks and approaches are inter- or transdisciplinary varies widely. This chapter focuses on the policy sciences tradition as the most comprehensive and transdisciplinary approach to provide insight and a map for action into real-world policy problems. This approach is intended to provide knowledge both "of" and "in" the public policy processes, situating the policy sciences between traditional academic approaches to knowledge production and the needs of society for policy-relevant information to aid in decision-making.

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The policy sciences are grounded in a pragmatic commitment to improving decision-making. The distinctive outlook of the policy sciences is problem-oriented, contextual, and multimethod (Lasswell 1971; Brewer & DeLeon 1983; Brunner 1997; Clark 2002). Notably, policy sciences do not shy away from the normative aspects of public policy. Instead, policy sciences integrate the normative aspects of decisions and decision-making into policy analysis. This means that policy scientists are explicitly motivated to advance public or private policy goals (as opposed to being driven by theory development or description). They are aware of the complex milieu in which any decision or social process takes place (as opposed to a narrow focus only on participants or only on power dynamics). And they purposefully use a range of methods to improve the policy process at hand, as opposed to applying a single method to all circumstances (e.g., cost-benefit analysis, statistical analysis, social network analysis; Brunner 2006, 2008). The approach is, by its nature, both interdisciplinary and transdisciplinary.

The policy sciences outlook entrains many individuals and groups. Some of these people self-identify as policy scientists and were trained by the intellectual forebears of the policy sciences, including Harold Lasswell and Myers McDougal and their collaborators. However, many other people and groups conduct inquiry consistent with the distinctive outlook of the policy sciences, and have created effective analogues to the frameworks and propositions that underlie the policy sciences approach. These implicit policy scientists are important in understanding both what the policy sciences approach is and how it operates in the world. The policy sciences do not require devout adherence to a formal set of practices, but only to a normative, problem-oriented, contextual, and multimethod outlook. Many of the concepts and ideas at the core of the policy sciences are compatible with the practices and modes of inquiry used by other policy practitioners and scholars who focus on resolving problems and improving outcomes in the real world, where multiple values, incomplete information, and limited cognitive abilities pose significant challenges.

The policy sciences take a pragmatic approach to understanding and resolving complex real-world problems. The policy sciences stand as a set of interdisciplinary frameworks and propositions that facilitate the integration of knowledge and practice. In effect, this means that the policy sciences draw freely from the methods of many conventional disciplines, as well as offer a framework to integrate the insights from those disciplines into a more holistic understanding of any policy process. This arguably suggests that the policy sciences as a whole constitute a transdisciplinary approach. Indeed, Raymond Miller (1982) cited the policy sciences as a leading example of a transdisciplinary approach in the social sciences. The policy sciences are a conceptual framework that transcends the narrow scope of other approaches to policy inquiry. As such, they offer the opportunity to break free from disciplinary orthodoxies. They use multiple disciplinary approaches and integrate those approaches in service of the kind of overarching synthesis implied by the term "transdisciplinarity."

The advantage of the policy sciences over comparable approaches is the policy sciences provide a logically comprehensive set of frameworks and propositions that call attention to the potentially relevant parts of any problem, decision process, or social context. In this sense, the policy sciences provide an instrument for integrating the insights of policy scholarship, social research, and practical experience across disciplines.

25.2 History of the Policy Sciences

The history of policy studies can be traced back to ancient Greece and Rome, where the need for advice and information in decision-making was recognized (DeLeon 1988). Yet, the tools and social/political conditions to sustain a concerted production of such advice and information did not exist until the late nineteenth century. Many credit Charles Merriam, a Progressive Era political scientist, as one of the first to study policy through his attempts to understand what governments do through the application of theory and practice (Theodoulou 2013). Merriam was noted for, among other things, advocating an applied sense of political science, focused on improving society through the application of interdisciplinary social research (DeLeon 1988).

But policy studies did not grow in popularity and application until the Progressive Era, when the field focused on the application of rational, scientific methods to the improvement of daily lives and society, including the application of scientific management to human behavior and government (Torgerson 1986). The tenets of scientific management represented an effort to improve society through science and the application of scientific principles in a bureaucratic setting. Scientific management, however, necessitates an unsuitable narrowing of context and methodologies as well as a partitioning off of normative considerations from policy studies that contradicts the policy sciences perspective. Paraphrasing Gunnell (1976), Torgerson argues that this separation of politics and administration is now largely considered "an illusion which tends to suppress critical questions about the political context in which policy analysis is applied" (1986, p. 38).

In part as a reaction to the dominance of scientific management and other reductionist methodologies in policy studies, Harold Lasswell argued in the 1950s for an approach to policy studies that was applied, interdisciplinary, and focused on the study of problems faced by government through the use of social science methods (Ascher 1986; Brunner 2006). The policy sciences are an ever-evolving collection of central theory that originated from Harold Lasswell, Myers McDougal, Abraham Kaplan, and other collaborators near the end of World War II (Lasswell 1956; Lasswell & Kaplan 1963; Lasswell & McDougal 1992). Harold Lasswell taught political science at the University of Chicago from 1922 to 1938. According to McDougal, by 1935 Lasswell had achieved a fairly complete formulation of the policy sciences, but did not formally crystalize what now serves as the basis for modern policy sciences until 1943 (Lasswell 2003). In 1943, Lasswell joined McDougal on the faculty at Yale University. Together, and with many collaborators, Lasswell and McDougal continued to develop what is now known as "the policy sciences" in policy studies circles and the "New Haven School of Jurisprudence" and "Policy-Oriented Jurisprudence" in legal circles.

25.3 An Overview of the Policy Sciences Approach and Central Theory

The policy sciences contain a set of interdisciplinary frameworks and a number of key propositions that provide policy analysts with a stable frame of reference from which to sample the context of any particular policy process (Lasswell 1971; Brunner 1997). Policy scientists refer to these evolving propositions and frameworks as central theory, and they form a heuristic that allows the analyst to quickly take stock of any policy process, to understand its basic outlines, and to identify key areas of inconsistency or missing information that can help direct the analyst's attention in productive ways. This approach is meant to be logically comprehensive and call attention to the potentially relevant parts of any problem, decision process, or social context. As a heuristic framework or "mental model," this provides a transdisciplinary instrument for integrating the insights of policy scholarship, social research, and practical experience across disciplines and substantive specialties.

The remainder of this section briefly examines two foundational principles of the policy sciences and the three most prominent policy sciences frameworks—problem orientation, the social process, and the decision process. These two principles and three frameworks do not exhaust this approach, but they do provide an important and sizable block of central theory that should prove illustrative to most readers. Furthermore, they provide readers a sense of the transdisciplinary nature of the policy sciences approach.

25.3.1 Principles

The policy sciences rest on several foundational principles, including a normative and a pragmatic principle. These foundational principles are interdisciplinary in nature, driving the transdisciplinary nature of the policy sciences from the ground up. For example, the emphasis on practical problem solving requires a normative commitment on the part of the analyst that is more than disciplinarily agnostic. Furthermore, the fundamental commitments of the policy sciences approach require analysts and practitioners to integrate types and ways of knowing to effectively contribute to solving problems.

25.3.1.1 The Normative Principle

This emphasizes the importance of people and perspectives, including the practitioner's standpoint. Instead of avoiding discussions of values to maintain a false sense of objectivity, the policy sciences embrace the discussion of values as necessary for honest policy inquiry. Consequently, this approach recommends that the practitioner engage in self-orientation to make explicit the values and assumptions that bias every researcher. The policy sciences also propose an explicit normative foundation in maximizing human dignity—the greatest possible participation in the shaping and sharing of policy outcomes—as the central goal of any policy process.

25.3.1.2 The Pragmatic Principle

The policy sciences aim to maximize the functional value of knowledge as opposed to developing generalized causal relationships or theory. A major component is a focus on problems instead of preconceived solutions or methodological approaches. Policy sciences research and practice emphasize practical insights into real-world problems and the invention and evaluation of alternatives to resolve those problems, as opposed to generalized theory development or methodological orthodoxy. They also emphasize the unique context—the empirical, social, political, and human reality—of every policy problem. Their use is not intended to narrow the scope of inquiry, but to continually call attention to what is left out of our evolving understanding of any particular situation.

25.3.2 Problem Orientation

Problem orientation refers to two important aspects of the policy sciences: (1) a philosophical focus on problems as opposed to methods or solutions, and (2) a heuristic framework designed to call the analyst's attention to the many potentially relevant aspects of any problem. Focusing on the problems as the central point of inquiry helps circumvent cognitive "blind spots" that often lead the investigator to fall back on what he or she already knows—which may or may not be relevant to the situation at hand. Two common blind spots are focusing on solutions and methods instead of problems. For example, many scholars try to apply ideas that have worked in the past to current problems, emphasizing the solution as a theoretical development instead of accounting for the unique context of the problem. Other scholars emphasize a particular methodology as relevant to all questions regardless of the situation. For example, some cost-benefit analysts reduce all policy problems to relationships of economic wealth, thereby defining away noneconomic values, such as justice or respect, which may prove central to a problem. In contrast, being problem-oriented means that the problem, not a preferred solution or methodology, should guide inquiry. This may necessitate drawing on expertise beyond the analyst's personal knowledge and methodological training in order to improve outcomes. As a framework and approach, the problem orientation breaks analysts out of their disciplinary and/or preconceived notions of the problem under inquiry, in effect asking analysts to be transdisciplinary in their approach to understanding and addressing problems.

As a heuristic framework, the problem orientation consists of a set of five intellectual tasks that allow the analyst to logically explore what aspects of a problem might prove important in any particular context, without respect to disciplinary bounds or foci. The complexity of many policy problems and the cognitive biases that plague "intuition" make the following framework quite useful in disciplining inquiry by systematically calling attention to the functional aspects of any problem. An analyst should not perform the tasks mechanically or in a serial fashion, but rather use the concepts to facilitate the organization of information and to call attention to neglected aspects of the problem by moving back and forth between the tasks so they mutually inform one another.

Task 1: Clarifying goals. In problem orientation, the first task of the practitioner is to clarify goals and identify preferred outcomes—a deceptively simple task. Goal clarification requires an understanding of the complex, overlapping, and sometimes contradictory goals of the relevant community engaged in or affected by a decision process. While the goals of authoritative decisions might be easily identifiable in written documents such as congressional laws or administrative regulations, policy scientists explore the perspectives of participants and may revise these goals according to distinctions such as formal/informal, instrumental/intrinsic, common interest/special interest, appropriate/inappropriate, valid/invalid, substantive/procedural, and so forth. Goal clarification is inherently based in the normative principle of the policy sciences discussed above.

Task 2: Describing trends. In order to evaluate progress (or lack of progress) toward a goal, an analyst must empirically assess the context, drawing from different types and ways of knowing. If the goal is to protect public health while maintaining industrial productivity, analysts need current and historical information on public health risks/impacts and industrial productivity/sustainability to understand progress or lack thereof toward the identified goals. Information on trends might include the biophysical, social, and decision-making aspects of a given issue (see the social process and decision process discussions below for a brief introduction to logical frameworks for identifying all potentially relevant aspects of any social or decision context). Furthermore, analysts must integrate such varied information into a holistic evaluation of progress, or lack thereof. Thus, describing trends requires careful consideration of the relevance of any piece of information to the identified goals—otherwise analysts have no logical basis for determining what information actually matters in identifying or resolving a problem.

Task 3: Analyzing conditions. To understand a policy problem and leverage potential alternatives to the status quo, analysts must understand why the identified trends have occurred and what factors underlie any discrepancies between trends and goals. Analyzing conditions requires empirical data of the context and the rational argument to understand each of the relevant trends, thereby undermining groundless assertions that might represent researcher and/or disciplinary bias. Conditions often cannot be established with as much certainty as trend data, but grounding the analysis of conditions in the empirical evidence preserves the focus on understanding the problem.

Task 4: Projecting developments. This task takes trend data and projects them into the future based on an understanding of the factors conditioning those trends. Projections, along with trends, are critical for identifying a problem by comparing them with the desired state of affairs identified in the goal-clarification task. Projections can include causal modeling and prediction, but are not limited to mathematical or quantitative techniques. When projecting trends and conditions, a range of scenarios should be considered to expand rather than contract knowledge of the problem at hand.

Task 5: Inventing, evaluating, and selecting alternatives. After identifying a problem through the first four tasks, the analyst can leverage the conditioning factors identified to determine options for more fully realizing the clarified goal. It is best to present a range of alternatives along with their benefits and drawbacks for decision makers to choose based on their own criteria.

The systematic focus on problems within the policy sciences via the problem orientation's use of logically interrelated tasks forces analysts out of disciplinary understandings that stymie problem solving. As Clark (2002, pp. 2–3) argues, "Conventional approaches tend to simplify policy problems, misconstrue some vital part of the context or overlook the context altogether . . . [in part because we may be] unduly preoccupied with or entrapped by some mental construct."

25.3.3 The Social Process

The social process is a framework meant to clarify the context in which all problems occur and all decisions are made. The policy sciences postulate a manageable list of concepts by which to organize information about any policy process (Lasswell 1971). The "social process" in the policy sciences refers to a set of seven conceptual categories that allow the analyst to logically explore the rich context in which humans interact and problems occur. The social process framework is meant to clarify the complex sociopolitical context of human action by providing a logically comprehensive set of categories that call attention to all elements of the social and political environment that are potentially relevant to understanding any policy problem. This framework is particularly useful in policy inquiry because of the incomplete information, cognitive limitations, and disciplinary biases that plague all analysts. The following categories are not meant to be prescriptive or deterministic, but rather are meant to discipline inquiry by systematically calling attention to the potentially relevant aspects of the sociopolitical environment. An analyst should not use these categories mechanically or in a serial fashion, but rather use the concepts to facilitate the organization of information and to call attention to neglected aspects of the sociopolitical context by moving back and forth between the tasks to further clarify the context in which a policy problem has evolved.

1. *Participants* include the individuals, groups, and/or institutions involved in a policy process. At risk of stating the obvious, people are fundamentally important to all human interaction. Yet people are notably absent from, or treated separately within, many theoretical models of policy inquiry and many conventional and disciplinarily focused approaches to policy inquiry. The key of this category is to assemble a holistic understanding of all the individuals and groups relevant in any policy process.
2. *Perspectives* are the subjective orientations of all relevant participants in a policy process. Perspectives include the identifications, demands, and supporting expectations of individuals, groups, and/or institutions. Identifications for any particular participant can be diverse. The key is to highlight the identifications relevant for a particular policy process. For example, a mayor's identification as a businessperson, a family person, or a veteran may all potentially be relevant to decisions made about financial support for a hospital. However, his or her identification as a golfer or an alumnus of his or her alma mater may not hold any relevance to the policy process at hand. It is the task of the analyst to judge what is and is not relevant.

   Demands include the values desired by any participant in a policy process relevant to his or her identifications, and are very closely related to the goal clarification task in the problem orientation. Again, it is important to narrow the full range of demands of any particular participant to those relevant to the policy process at hand. For example, a mayor considering financial support for a hospital may have relevant value demands relating to the location of the hospital, the economic impact it may have on the community, the types of services provided by the hospital, or the type or style of construction. Even personal value demands may come into play. For example, the mayor may wish to be respected as a community leader or may have religious beliefs about the right thing to do in taking care of fellow community members. All such value demands may help to understand and explain a particular policy process. But other value demands unrelated to the hospital may not be relevant to the policy process at hand, even if emphasized strongly by the mayor, such as the mayor's demand for greater financial support for local industry or commerce.

   Supporting expectations typically flow from the identifications and value demands of a participant in the policy process. Typically a policy participant expects individual value demands to either be promoted or denied by a proposed policy. As suggested in the goal clarification task in the problem orientation, the perspectives of participants are quite relevant to defining policy goals. Perspectives are a key feature of the social process that are typically underemphasized, but are critical to understanding the policy process.

3. *Situations* refer to the contexts in which participants interact and make value demands, and are critical to understanding the social process. Situations can include the biophysical, temporal, institutional, political, and perhaps other contexts in which a social process occurs. For example, a demand for greater access to water may take on different significance in an organized institutional environment (e.g., in the context of Colorado water law) versus a disorganized context (e.g., in the context of a country with weak systems of resource allocation and control). It may also take on different significance in a political context of crisis (e.g., a severe long-term drought) versus noncrisis (e.g., times of plenty).
4. *Base values* can be thought of as resources available to any given policy participant. But the policy sciences include resources beyond those typical in conventional policy analysis—namely, money and power. Indeed, the policy sciences propose another framework for thinking of values that we do not cover here, but which includes the following value categories: affection, enlightenment, power, rectitude, respect, skill, wealth, and well-being. For example, a priest may have base values of affection (e.g., the caring connection of parishioners), rectitude (e.g., a standing to speak of what is ethical/right and wrong), and respect (e.g., the social or personal deference other community members may have toward a religious figure) that he can draw on to play an important role in a social process. A university professor may draw more heavily on enlightenment, skill, and respect. And an environmentalist may draw on affection, rectitude, and well-being. While such values must be specified in detail relevant to the policy process at hand, a full understanding of any social process requires an understanding of much more than the political power and economic wealth dynamics at play in a social process.
5. *Strategies* are the means employed by participants in a social process to pursue their values and outcome demands. There are many ways to meaningfully organize understanding of different types of strategies. For current purposes, it is enough to emphasize the importance of understanding strategies as one component of the broader social process. For example, a policy participant might pursue a coercive strategy, such as a lawsuit or a regulation, in pursuit of a policy goal. But the same policy participant might instead pursue a persuasive strategy, such as political lobbying or an education/information campaign, in pursuit of the same policy goal. The choice of one strategy over another is significant for understanding the broader social process.
6. *Outcomes* are the near-term consequences of participants interacting in a social process. Outcomes are typically understood in terms of relative value gains or losses of policy participants. For example, if a land trust purchases a conservation easement on 100,000 acres of ranchland, the easement holders may have increased their power and wealth values such that they can better achieve their conservation mission.
7. *Effects* are the long-term consequences of participants interacting in a policy process. Effects are less likely to be tied to the values of policy participants, and more likely to

integrate the empirical consequences of decisions made in a social process. In the land trust example above, effects are more likely to include things such as the rehabilitation of riparian areas, the preservation of rare species, the prevention of subdivision and development, or increased wildlife populations. To illustrate the difference between outcomes and effects, consider the long-term consequences if the hypothetical land trust purchases 100,000 acres of environmentally marginal land versus purchasing 100,000 acres of prime wildlife habitat.

While the social process focuses on the human element of a complex social dynamic—namely participants—it does so by asking the analyst to consider a broad set of categories that facilitate crossing traditional disciplinary boundaries. The social process is a logically comprehensive approach to understanding stakeholders within policy analysis, and it allows analysts to develop a more holistic understanding of the complex social process by overcoming cognitive limitations, disciplinary biases, and incomplete information.

25.3.4 The Decision Process

Because the distinctive focus of policy scholars is on the process of decision-making, the policy sciences provide another framework that proposes a manageable list of decision functions as a cognitive tool to organize information about decisions and call attention to the potentially relevant aspects of any decision-making process (Lasswell 1956). The "decision process" in the policy sciences refers to six decision functions that facilitate the organization of information and call attention to neglected aspects of the decision context relevant to the problem at hand (e.g., the promotion function, or politics, is often underemphasized in favor of the intelligence function, or information, in conventional policy analysis).

This heuristic is probably the most commonly used and most commonly misunderstood aspect of the policy sciences approach within the broader field of policy studies. Namely, the decision process framework does not imply a formal and linear model of how decisions are made. Rather, the framework is intended as a logically comprehensive set of categories that allows for a more systematic, comprehensive, and transdisciplinary understanding of any particular policy context. Specific disciplines and subfields have peeled off particular aspects of the decision process as a key focus of inquiry (e.g., political science has devoted a tremendous amount of scholarly work to implementation and agenda setting, while economics has developed specific disciplinary tools for appraisal). We note that while these focused disciplinary inquiries have developed a substantial body of knowledge and theory regarding specific functions, practical problem solving is better served by a complete understanding of these functions and how they fit together to develop a transdisciplinary, holistic assessment of the decision-making process.

The *intelligence* function refers to the gathering, processing, and dissemination of information. Intelligence outcomes might include scientific reports, news stories, or economic forecasts. A key question in this function is, "What kind of intelligence is being used in a decision process and by whom?" This function is particularly important in the trend description task of the problem orientation. Useful intelligence can lead to well-informed policymaking, but not all intelligence is useful. In many cases, there is so much intelligence available surrounding a particular policy problem that the challenge is not finding information, but screening and filtering it to ensure it is relevant and dependable. From an analytical perspective, the intelligence function is further complicated as some policy participants substitute the promotion function for the intelligence function. Such substitution can undermine the intelligence function. This is a pervasive element of modern policymaking and includes examples such as push polling, agenda-driven think tanks, propaganda, and political spin. Nonetheless, these functions are treated as separate categories to help provide clarity to the policy scientist.

The *promotion* function refers to lobbying efforts and the use of intelligence to select among alternative courses of action. Key questions in this function are, "Which policy participants are urging which course of action?" and "What values does that course of action serve?" In its most democratic form, promotion is simply various participants in the policy process using their base values to pursue their value demands. The promotion function is particularly insightful in understanding the extent to which a decision process comports with the explicit normative principle proposed by the policy sciences to maximize human dignity—the greatest possible participation in the shaping and sharing of policy outcomes. To realize this ideal, the promotion function should be open, participatory, and transparent. In reality, the promotion function in many decision processes is characterized by special interests pursuing their agendas in a controlled environment.

The *prescription* function refers to the rules or laws decided on in a decision process. Prescriptive outcomes might include a law passed by Congress or a regulation promulgated by an agency, but they need not be formal law as generally understood in highly developed modern societies. A prescription crystallizes the expectations and demands of policy participants. However, simply developing a prescription does not address a policy problem, as it must be implemented to achieve the desired outcomes and effects.

The *implementation* function is actually a combination of two functions in the policy sciences literature—*invocation* and *application*. Implementation refers to conformance or nonconformance with the prescription. These outcomes might include enforcement action by regulatory bodies or the police, judicial decisions, conformance with mandated deadlines, and so forth. Once a prescription is formally approved or adopted, an incredible amount of implementation activity follows. This activity can determine the success or failure of a prescription. And many savvy policy participants, knowing this, engage in the implementation function to pursue their value demands.

The *appraisal* function refers to judgments of the success or failure of the prescription. Appraisal judgments can often be found in official reports or investigations and often play an intelligence role for future iterations of decision. While some decisions explicitly call for appraisal activities to determine midcourse corrections in implementing a prescription or to judge the effectiveness of the prescription itself, most do not. There are also only a handful of institutions focused on the appraisal function. For example, at the federal level in the United States, the Government Accountability Office specializes in this role. However, the history of a similar US government appraisal institution, the Office of Technology Assessment, suggests the difficulty involved in formally appraising prescriptions in the decision process. Most policy scientists specialize in this role, along with the intelligence function, in the decision process.

The *termination* function refers to the cancellation or succession of a prescription to make room for new practices. However, prescription termination is notoriously difficult, as most policies create a constituency whose values are served by that policy who will mobilize in support of it when threatened. There is rarely the political will to terminate even ineffective policies. As a consequence, the termination function stands as one of the most intractable functions in the decision process.

The decision process developed within the policy sciences has served as a starting point for many approaches within the broader field of policy studies. We note, however, that these derivatives tend to be more disciplinarily limited (e.g., the field of policy evaluation and termination is frequently tied to an economic approach to understanding both the problem and appraising performance). These disciplinary limitations are problematic because they, in effect, blind the analyst to potentially important aspects of the decision-making process, the problem itself, or the actors and institutions involved. By using the more holistic and transdisciplinary decision process described above, a policy analyst is forced out of his or her comfort zone to consider relevant information in a comprehensive and systematic way.

25.4 The Policy Sciences in Critical Context

Despite the advantages described above, numerous policy scholars have criticized the policy sciences (e.g., Morgenthau 1952; Jenkins-Smith & Sabatier 1993; Falk 1995; Sabatier 1999). After reviewing all major critiques, Matt Auer (2007) classified the critiques into five categorical arguments: the linearity critiques, public expectations and the policy cycle, decision process as top-down and legalistic, the insufficient comprehensives of the decision process, and the decision process and causal theory.

The critiques of insufficient comprehensiveness and decision process as a causal theory are directly related to the transdisciplinary nature of the policy sciences. Auer (2007) concludes his analysis by suggesting that all major critiques of the policy sciences stem from either a partial understanding or misinterpretation of policy sciences literature and thought. The underlying problem in the critiques of insufficient comprehensiveness and decision process as a causal theory stems from treating the transdisciplinary policy sciences as if they were a conventional discipline—a frequently problematic occurrence in inter- and transdisciplinary approaches. For example, these frameworks do not imply linearity as Jenkins-Smith and Sabatier (1993) claim. Such linearity only exists when Jenkins-Smith and Sabatier (1993) mistakenly treat the decision process framework as a predictive theory—a conventional disciplinarian critique that fails to see the decision process framework as one of the heuristic devices of a broader transdisciplinary approach.

Certainly, there are meaningful critiques that scholars have leveled at the policy sciences. Yet these critiques are made from both the specific goals and interests of individual authors, many of which may not align with the broader mission of the policy sciences approach, and the application of disciplinary-specific criteria to an inherently transdisciplinary approach. It is worth noting that such critiques do not lessen the value of the policy sciences as a transdisciplinary approach, but rather exist because of it.

25.5 Conclusion

In the experience of the authors, the policy sciences "work" because the transdisciplinary nature of the policy sciences requires analysts and practitioners to integrate types and ways of knowing to effectively contribute to solving problems. In the words of Lasswell, "To some extent we are all blind and no doubt will remain so. But there are degrees of impairment, and so far as decision outcomes are concerned, it is the responsibility of the policy scientist to assist in the reduction of impairment" (Lasswell 1971). The policy sciences encourage analysts to investigate problems explicitly from an interdisciplinary stance, due to both the nature of its underlying propositions and the interdisciplinary frameworks developed to guide the analyst in his or her work. Our ability to contribute meaningfully to the improvement of decision-making outcomes, regardless of the role we play in the decision-making process, is directly linked to the comprehensive, systematic, and transdisciplinary nature of the policy sciences. The value of the policy sciences is also reflected in their ability to intellectually evolve and efficiently and effectively incorporate new knowledge, new experiences, and new disciplines into our own mental model of the policy process. In that sense the policy sciences are transdisciplinary because they are not fixed in substance or even in time. Rather, they facilitate an integrative and synthetic understanding of any policy process through practiced use of the stable frame of reference of the policy sciences frameworks and propositions.

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CHAPTER 26

SUSTAINABILITY SCIENCES
Political and Epistemological Approaches

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26.1 Introduction

The concept of sustainability refers to the human awakening to the fact of the finite nature of natural resources. This awakening occurred as a political and social process that placed the following factors on the development agenda: the limits of the biosphere; a synchronic solidarity with the current generation and a diachronic solidarity with future generations; the need for assured access to basic conditions of universal healthcare and education; and a respect for customs and traditions, as well as the legitimacy of institutions (Sachs 2006). These conditions are contextualized in two interdependent dimensions: (1) society and nature, and (2) local and global scales.

This process (especially since 1992) led to the creation of a research field, naturally interdisciplinary, involving transdisciplinary interactions, that will be referred to here as the sustainability sciences. This chapter discusses the epistemological character of this field with particular attention to its interdisciplinary and transdisciplinary dimensions. As part of this objective, we discuss the historical development of environmental issues and the international political movement that culminated in the perspective of sustainability; the evolution of sustainability-themed scientific analyses and its emergence as a research field; and finally the political and epistemological aspects that shape the sustainability sciences.

The interdependence between society and nature refers to the consequences of human activities on ecological systems and their implications for environmental and human health as well as the capacity for resilience across human activities. Interdependence between local and global scales concerns the imbalance in natural resource appropriation, resulting from political and economic asymmetries between regions and countries, with benefits and negative impacts that are unequally distributed across communities. In other words, the disproportionate use of natural resources has generated wealth for a relatively small portion of global society, while the side effects from these uses are distributed throughout the world, principally affecting the most vulnerable portions of societies. This awakening, which was sparked by environmental disasters as well as economic and energy crises, provoked the rise

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of environmental movements and intergovernmental reactions such as the conferences in Stockholm in 1972 and Rio de Janeiro in 1992. As a result, new national institutions as well as legal and institutional environmental frameworks were constructed, including academic and scientific structures to host undergraduate and graduate courses involving environmental themes.

In recent years scientific research associated with sustainability has increased exponentially. In particular this process resulted in the formation of databases and a large number of publications, scientific journals, and books, representing not only the rise of this new theme but also the growth of a research field that established itself across the international scientific community. This upsurge is evidenced by the analysis of Kajikawa et al. (2014) in the Thompson Reuters and Web of Science databases, which observed the increase in the number of published documents involving sustainability. The authors also identified the growth of journals dedicated to the theme of sustainability and the wide diversity of groups of researchers in the form of research clusters, hubs, and networks. The focus of these analyses includes not only environmental issues but also social and economic systems, almost always spanning numerous disciplines, revealing a broad and complex research field. Overall, this has been denominated as sustainability science, but from the perspective raised here it is better understood as the sustainability *sciences*.

Sustainability science was proposed by Kates et al. in 2001, with a focus on the interactions between nature and society and with the aim of having integrated contributions from different disciplines to sustainability. However, this design results in a fundamental contradiction: Is it possible to outline a science of sustainability? What topics (subjects) would compose it? Which sciences would make up the field of sustainability? Should we start from the design of a sustainability science in order to define which topics to include in its composition? Or, conversely, should we start from the range of topics necessary for its analysis, considering the various sciences needed? The first option assumes the configuration of a sustainability science. The second involves a research field composed of various sciences and technologies as well as humanities, altogether making the sustainability sciences.

This second option justifies what, according to König (2015), implies conceptual changes in knowledge and science practices with a critical epistemology considering the combination of two large branches of sciences, social and natural, with the humanities. For this reason sustainability sciences encompass contextualized approaches with interdisciplinary foundations and transdisciplinary interactions (Clark & Dickson 2003; Jerneck et al. 2011).

26.2 Historical, Political, and Social Evolution

A series of landmark meetings, social movements, and academic work represent the beginning of an era that questioned the classical model of development. The Great Smog of London in 1952 compelled the passage of the first air pollution law in 1956 (EUA, EPA & APTI 1992). In the book *Silent Spring*, the US biologist Rachel Carson expressed her concerns related to the environmental risks, with serious consequences for human and environmental health, resulting from the chemical substances found in pesticides (Carson 1962). Other reports referenced cadmium and mercury contamination of the Minamata and Niigata bays in Japan in 1956, and their discovery in the food chain and regional inhabitants (Timothy 2001). The publication of *Limits to Growth* in 1968 alerted countries, via mathematical modeling, about the incompatibility of their style of development and maintenance of natural resources (Meadows et al. 1972). The oil crisis highlighted that the fuel of the modern economy, which up until the 1970s was considered an abundant and inexhaustible resource, was indeed finite, leading to the questioning of development models with energy matrices based on fossil fuels (EPA 1992).

From these historic events, and especially *The Limits to Growth*, the conferences that followed continued to discuss the constraints of natural resources, the limits of technological solutions, and the social and political contrasts challenging global economic growth. The UN Conference on the Human Environment, proposed by the so-called developed countries held in Stockholm in 1972, had deep links to the Meadow's report. A significant number of countries participated in this first international environmental event, which was characterized by the necessity of including as many parts of society as possible in defining the goals around human and environmental challenges. This introduced the need for environmental education as a fundamental condition when thinking about a sustainable future. Out of Stockholm also came the concept of *ecodevelopment*, which in 1987 became labeled *sustainable development* (WCED 1987).

In the years that followed, with sustainable development always as the focus, several more international conferences were convened, including Habitat I in Vancouver in 1976, the Intergovernmental Conference on Environmental Education in Tbilisi in 1977, and the International Conference on Health Promotion in Ottawa in 1986. Twenty years after Stockholm, the UN Conference on the Environment and Development in Rio de Janeiro in 1992, using *Our Common Future* (WCED 1987) as its basis, linked development and the environment as inseparable. It called attention to the fact that any city, region, or country, through its development, depends on a sustainable resource base supported by the tripod of social justice, a viable economy, and ecological equilibrium.

The Rio-92 conference was followed by the UN Conference on Population and Development in Cairo in 1994, the Conference of Social Development in Copenhagen in 1995, and Habitat II in Istanbul in 1996, all of which discussed the linkages between urban and social problems with environmental challenges. In 1997, 20 years after Tbilisi, the Conference on the Environment and Society was held in Thessaloniki, where education and awareness served as the principle instruments for furthering sustainability. Also in 1997, Rio + 5 took stock of the challenges met, those that persisted, and those emerging. The discussion continued in 2002 with Rio + 10 in Johannesburg, which called attention to questions related to poverty, reiterating that the collective commitments from previous conferences need to be respected, especially by developed countries. Such commitments included financial investments of 0.7% of GDP in planning and programs aimed at assisting poorer regions. Then in 2012, Rio + 20 sought to reinvigorate these previous commitments and renew political pledges for sustainable development. From Rio + 20 came lines of thinking such as the green economy, the need to eradicate poverty, and an institutional framework for sustainable development (Philippi et al. 2014).

Lastly, representatives of more than 170 countries endorsed the 2015 Paris agreement to cut carbon emissions. As the *Guardian* noted, France's president said, "There is no turning back" (Goldenberg & Neslen 2016). Taken together, these conferences represent an international movement that goes beyond high-level diplomacy and exclusively environmental concerns (Callicott 2010). If sustainability appears as a scientific paradigm, it is primarily associated with a social paradigm that induces a thought of international politics and policies. It can be argued that this represents a social trend, and although its future is uncertain, it has its origin in a crisis between society and nature on both local and global scales.

26.3 The Constitution of a Field of Knowledge

As described in the previous section, sustainability emerged as a social and political phenomenon and became established through the aforementioned UN Conferences. At the same time, the field of research surged, encompassing and transcending various bodies of knowledge and disciplines. As observed by Clark and Dickson (2003), from the 1990s onward a number of movements were formed to promote a reconciliation of science and technology toward sustainability. Two perspectives are highlighted herein, which occur in different levels but are not in opposition to each other: a more technical perspective, and a more holistic one. In the first, technology assists in developing better ways to use natural resources and in reducing the impacts of social activities on the environment. In the second, it is necessary to remake science from the perspective of sustainability. The focus is on the dynamic interactions between nature and society, evolving two-way influences whereby society shapes the environment and is shaped by it.

This role of science in sustainability studies was identified by Kajikawa et al. (2014) through a database analysis of Thompson Reuters and the Web of Science. Using the terms "sustainability" or "sustainable," the authors identified the number of publications beginning around 1990 and then considerably accelerating at the beginning of the present millennium. This phenomenon shows the large scope of this research field, transcending various disciplines, but which at the same time exhibits unique characteristics that differentiate it from traditional fields of knowledge.

Repeating the same search in April 2016, we found about 299,000 documents from Scopus, associated with various fields of knowledge (Figure 26.1).[1] In the Web of Science, the same terms register around 240,000 documents. In both databases, the first instance of "sustainability" appears in 1974. The largest growth occurs after 1992 and markedly increases after 2000 (Figure 26.2).

Sachs (2006) suggests that sustainability can be expressed as a balance and interdependence between environmental, social, and economic dimensions. This balance and interdependence is shown in Figures 26.1 and 26.3, where these three dimensions are represented by environmental, engineering, social, agricultural, and biological sciences, among others.

[1] The category "Other" comprises the following areas: decision sciences; arts and humanities; physics and astronomy; mathematics; immunology and microbiology; multidisciplinary; nursing; psychology; pharmacology; toxicology and pharmaceutics; health professions; veterinary; undefined; neuroscience; dentistry; medicine; materials science.

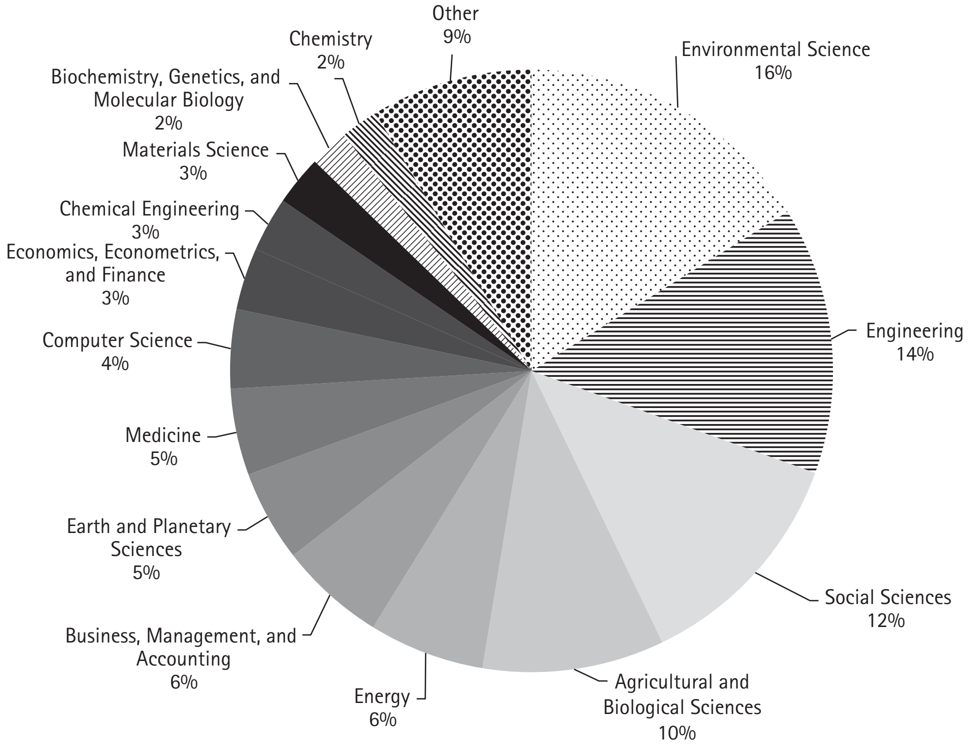

FIGURE 26.1 Fields involved in the theme of "sustainability" from Scopus.

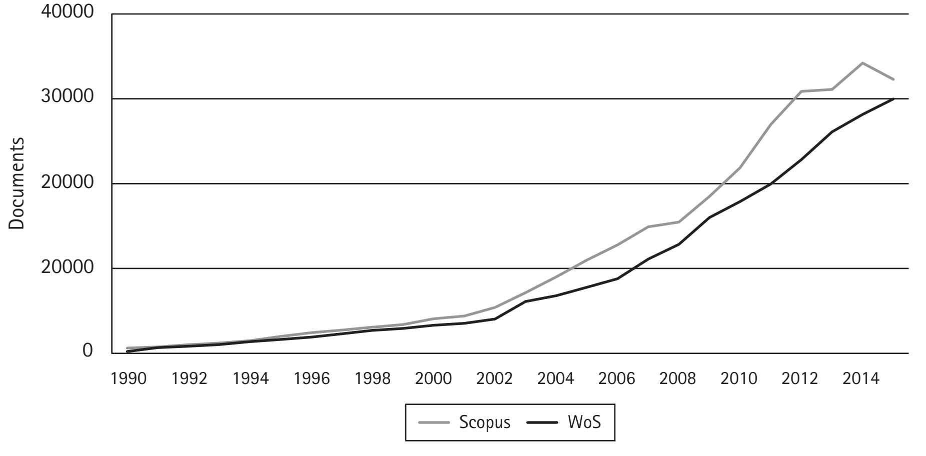

FIGURE 26.2 Growth in number of documents containing the words "sustainability" or "sustainable" since 1992 in Scopus or Web of Science.

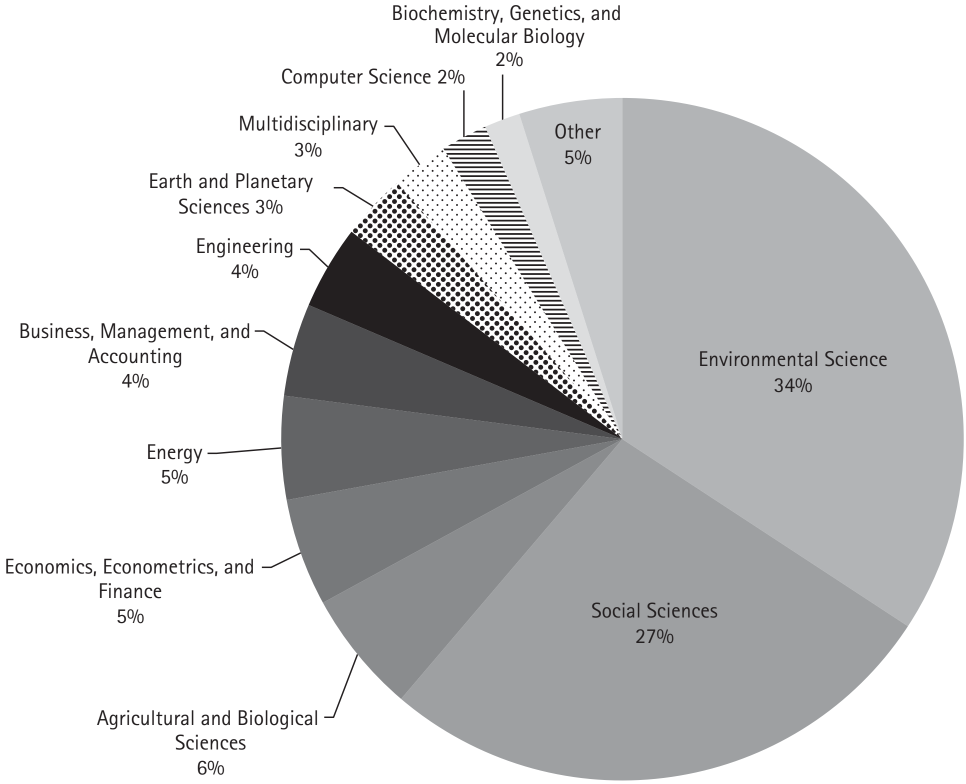

FIGURE 26.3 Fields involved in the theme of "sustainability science" in the Scopus database.

When only searching for "sustainability science" in Scopus, 776 documents are found (Figure 26.3), while in Web of Science, the number is 629. In both bases, 2001 is the year in which the first publications appear, then the expression gained traction and the number of publications increased considerably (Figure 26.4). There is a similarity between the first and second searches. In both cases more than 60% of these are articles, 18% are conference papers, and 20% are other kinds of documents (such as books, book chapters, review, etc.).

The comparison between Figure 26.1 and Figure 26.3 reveals the fact that sustainability is treated as a field of research by many more disciplines than when it is perceived as a science, that is, such as a discipline. When comparing the distribution across the field when searching for "sustainability or sustainable" (Figure 26.1) 50% of the distribution is spread across several disciplines. The remaining 50% is distributed among environmental, engineering, social, agricultural, and biological sciences. In searches for "sustainability science" (Figure 26.3) environmental and social sciences dominate, with over 60% in these two areas, which means that most areas are concerned with research on sustainability, but do not have the same concern with epistemological discussions about the constitution of this as a research field. In this regard, it is important to highlight the low percentage of engineering, agricultural, and biological sciences in "sustainability science" when compared with the previous search, using the terms "sustainability" or "sustainable."

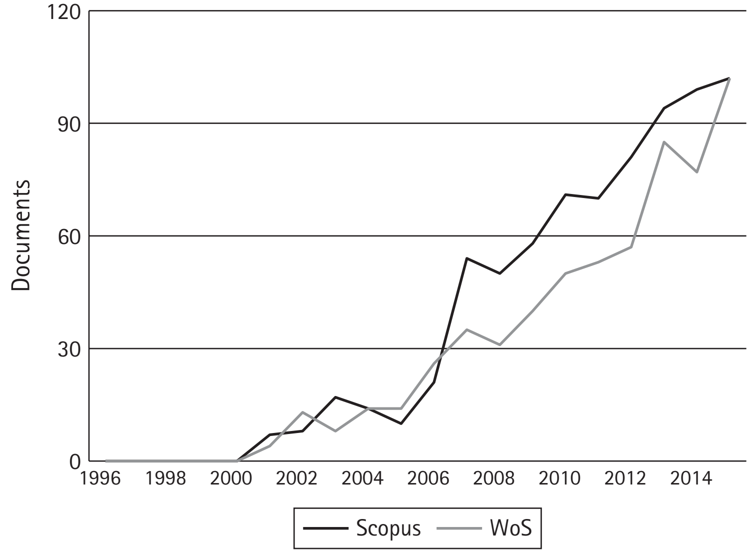

FIGURE 26.4 Growth since 1992 in the number of documents containing "sustainability science" in Scopus and Web of Science.

The results presented in Figure 26.1 confirm what is stated by Krohn (this volume): "real-world cases necessarily integrate heterogeneous knowledge bases, be these gathered under the institutional cover of a discipline or not. Any research field or research project that addresses real-world problems is considered to be essentially interdisciplinary" (pp. 32–33).

On the other hand, Figure 26.3 represents the efforts of some disciplines to develop a new science. Also according to Krohn, such efforts "define interdisciplinarity on the basis of and as a derivative of the disciplinary structure of knowledge."

Similarly, the greater frequency of "sustainability" in several disciplines is an indicator of an emerging research field that requires several approaches, methods, and expertise. On the other hand, due to its spread, breadth, and complexity, this growth brings tension to the disciplines. It is a field that requires new knowledge arising from the collaboration between disciplines (therefore interdisciplinary). This collaboration demands that the disciplines reinvent themselves. Sustainability is clearly a multidimensional subject not limited to any single approach brought by the disciplines. Whenever a discipline treats sustainability it alone will face the tension of making a multidimensional subject confined to restricted worldviews. In this context, this tension is not restricted to methods and epistemological assumptions, but it acts precisely in the ontology of production and organization of knowledge.

In sum, the figures show two characteristics of this research field, which point toward section 26.5 of this chapter, where an epistemological account of sustainability is offered. First, interdisciplinarity emerged from the collaboration between several disciplines. Second, the transdisciplinary aspects of sustainability evolve inseparably from the historical, political, and social processes surrounding it. The union of these two features makes sustainability sciences both an interscience and a field of research for individual disciplines. Therefore, by definition, as evidenced in Figure 26.1 and Figure 26.3, it is more logical to think of sustainability as a research field (sustainability sciences) subject to several sciences than a single scientific discipline.

26.4 Necessary Interconnections and Interactions

As the previous sections show, sustainability developed in parallel with a historical process, as a social paradigm, and as a field of knowledge involving diverse areas of science. The term implies knowledge about biology, physics, chemistry, and hydrological processes, among other fields, and implies relating these to social, political, and economic problems of management at various levels, including urban and rural as well as public and private (Philippi Jr et al., 2013). Beyond this diversity of themes, it simultaneously covers a global scale with a systematic focus. At the same time, it recognizes the importance of the articulation of non-scientific forms of knowledge for research problems, especially at the local scale. It is therefore a field that comprises a wide spectrum of knowledge and practices that stand alongside the human sciences, culture, philosophy, and religion. Therefore, it challenges disciplinary presumptions in favor of a cooperative model.

First, this complexity implies significant changes in models of disciplinary knowledge production. Sustainability sciences require presumptions that investigate causes that range across social, technological, economic, political, or cultural origins. A water pollution problem, for instance, can be related to community habits, misunderstood use of technology, inadequate regulatory systems, or lack of investments. Therefore, a clear contextualization is imperative to sustainability analysis. This implies identifying variables beyond those recognized by traditional scientific approaches to a research problem, according to the scientific methods.

Second, sustainability sciences also involve transdisciplinary interactions between Western science and traditional ecological knowledge (TEK), for example, leveraging the practical experience and process of knowledge encoded in rituals and in the cultural practices of everyday life as well as the collective wisdom of adaptation to change over time (Berkes et al. 2000). In this sense, the sustainability sciences intrinsically criticize the existing rational scientific models, prompting the construction of a more cooperative rather than hegemonic form of knowledge. This perspective, in addition to giving rise to the rapprochement of various sciences, also presupposes transdisciplinarity, since it is contextualized going beyond scientific knowledge. Klein (2010, p. 25), based on Stokols et al. (2008), states, "TD science is a collaborative form of 'transcendent interdisciplinary research' that creates new methodological and theoretical frameworks for defining and analyzing social, economic, political, environmental, and institutional factors in health and well-being."

The connections between society and nature have been characterized by Holling and Sanderson (1996) and Davidson-Hunt and Berkes (2003) as an interdependent process operating at different spatial and temporal scales. These are nonlinear and complex processes with high degrees of unpredictability. Due to these characteristics, environmental-social phenomena do not fall within the traditional epistemology schemata (positivism, pragmatism, functionalism, structuralism, phenomenology and historical materialism) that have been developed without considering these interdependencies by classical epistemologies. This, indeed, is an inherent condition in the ontology of the sustainability concept emerging throughout the world. It means not ignoring, but rather integrating, basic local needs such as combating poverty, changing consumptions patterns, land use and occupation, and a balance between urban and rural environments. Pertaining to global questions, it means integrating the consideration of natural resource use, biodiversity, CO_2 emissions and other pollutants, demographic dynamics, immigration policies, technology transfer, and cultural diversity.

26.5 Toward an Epistemology of Sustainability

The elements that constitute an epistemology of sustainability are those that produce an investigative method and research techniques that elaborate (either explicitly or implicitly) a worldview and constitute the nature of science, which in practice produces knowledge expressed socially and politically. Its conception of the world defines what is understood by knowledge and how it is perceived, constructing the vision of social reality and cognoscibility of the world. Through its method of investigation and its objectives and goals, it relates thought and reality, subject and object, and the relationship between objectivity and subjectivity (Faria 2012). Thus the question becomes, how does one arrange those elements into an epistemology for the sustainable sciences?

Frodeman (2013) notes that the disciplinary structure and epistemologies developed during the nineteenth and twentieth centuries are incompatible with the current social, economic, and environmental phenomena. Besides the methodological challenges in incorporating new societal demands, he highlights the importance of considering the role of knowledge required by contemporary challenges. It is not enough to make sure that a science is methodologically efficient, producing "useful" results. Science also needs to consciously reflect the future that is being constructed by the present. At the same time, the author notes the problem of the overproduction of academic knowledge—overproduction in the sense that knowledge can overwhelm the decision-making process. These questions are key challenges of sustainability.

Thus in sustainability sciences, the production of knowledge must derive from a conception of knowledge that is not circumscribed to the disciplinary domains, but transcends academic barriers and presupposes interaction with society and not just dissemination or outreach (Klein 2010). They must also overcome the reflexive inertia of the role of knowledge resulting from the rationalization of life and science (Fernandes 2010). In this manner, interdisciplinarity has a fundamental role to play as an exercise in self-reflection searching for the lost connections across the disciplines. At the same time, transdisciplinarity is essential to reinvent the capacity to reflect about life and to contribute to restore the capacity of science to reflect political and social views in an integrated manner. The development of a society cannot be measured solely by its technical progress; the ways in which it socializes and uses technology should also be considered for its central role in the achievement of an integral development, where technology usage promotes the advancement of social relations. Social, environmental, and political textures should be understood through the independencies between society and nature, as well as at the local and global scales that color these interactions. Useful scientific knowledge follows from this paradigm and from a priori conditions that are not scientific.

It also follows that sustainability sciences transcends the traditional and reductionist models of reality moving toward a contextualized form, searching for relations among its constituent parts, situated in particular socioenvironmental and political contexts. The mental instruments, consisting of concepts, and the material tools of analysis must be reconfigured in a transdisciplinary and interdisciplinary manner, by having professionals open to new approaches, accepting different visions, and understanding that the best outcomes will derive from joint discussion.

The immediate perception of reality does not derive from isolated and static phenomena, but is comprehended through a social construction of reality in a socioenvironmental context. This presupposes a critical comprehension of reality in a manner not dislodged from natural systems in relation to social systems. Social reality is composed of numerous dimensions and connections that are inaccessible from isolated scientific models. Reality only reveals its complexity through combinations of analyses that join material and nonmaterial aspects of reality (Raynaut 2011). As discussed in section 26.3, the characteristics of the sustainability sciences is that they call for several fields of knowledge (Figure 26.3), and they are truly connected to the historical, political, and social processes surrounding them. An example is urban issues and their relationship to land use, mobility, urban ecology, poverty and violence, among other issues.

In sum, understanding the world is impossible through single disciplinary domains or models decontextualized from operational realities. The world can only be known through a dialogue among conceptual disciplines of different types of knowledge and between nonscientific worldviews. The cognition of the world, social and natural, local and global, also depends on its materiality, considering the symbolic appropriations made by subjects through references that are cultural, political, ideological, and religious.

Through the conception of knowledge regarding the world in a new way, an investigative method defines the processes of dialogue and critique across inter- and transdisciplinary levels. Such a dialogue broadens the cooperative perception of what is real. It depends on the right conditions that cannot be reproduced, making each moment unique. The synthesis of knowledge is the element that emerges from the fundamental dialogue with *otherness*, manifesting itself in this cooperation and coproduction (Philippi et al. 2016). Therefore, the production of knowledge for sustainability is a process of collaborative learning based on both a vision and disciplinary knowledge in order to find the connections that reveal this new approach. The learning process happens from the collaboration between researchers and their relationship with the context. What once seemed like clutter and chaos, now acquires logic. The relation between subject (consciousness) and reality (material and nonmaterial) composes a whole (Raynaut 2011).

In this discussion, analysis is not conceived as disconnected from the phenomenon and its immediate reality. The capacity of understanding the world either through thought or by research instruments is dependent on symbolic elements. Objectivity depends not only on a material reality but also on the way the symbolic aspects are perceived by different scientific lenses.

Thus sustainability is not found in traditional disciplinary models of analysis, and does not emerge as a single science but as several sciences from various disciplines. It is constituted by a context and process of interactions among sciences, in a space between traditional scientific and nonscientific (e.g., TEK) knowledge. It is an opportunity to insist on consolidating a social and scientific paradigm: a solidarity with present and future generations.

At the same time, since the sustainability sciences emerge from empirical phenomena only understood in the past few decades, their development should include different perspectives from inter- and transdisciplinarity. They have to transcend ideological positions of how to combine sciences and social realities (such as Basarab [2002] and Morin's (1997) views). The sustainability sciences developed from contemporary realities that do not fit within preexisting conceptual frameworks and thus transcend the usual solutions found in such practices and debates.

However, interdisciplinarity as advocated here should not be sought solely through the concepts and methods of the various sciences' perspectives, but rather through the empirical phenomena that constitute their study. Integrating, interacting, and establishing relationships between the sciences represent important steps that recognize and facilitate such interdisciplinary work. Nevertheless, it is important to stress that this requires accompanied field work that connects such concepts. Similarly, transdisciplinarity cannot be disconnected from the empirical field from which it arises, under penalty of falling into mere ideology. Klein (this volume) identifies a taxonomy of transdisciplinarity consisting of three parts: transcendent, transgressive, and transformative. Using this taxonomy, it is clear that greater weight is given to ideological preconceptions than anything constituted from research in the field.

26.6 Conclusion

The sustainability is a multidimensional subject, a research approach to the natural, social, life and technological sciences, as well as traditional and practical knowledge. This view opens up room for the rise of new multi- and interdisciplinary fields, such as ecological economics, environmental health, sustainable engineering. These fields combine scientific knowledge from different disciplines to bring sustainability to their object of study. Sustainability becomes a bridge between disciplines that converge to solve complex problems such as climate change, biodiversity loss, deforestation, among others. In this model, the sustainability sciences, the convergence spaces are not only the attributes of the disciplines but also the characteristics that emanate from the research field.

The sustainability sciences constitute a field of knowledge born from a convergence of social, political, and economic worldviews. Therefore, this new research field has a knowledge dependent not only on several disciplines but also on a new and integrative notion of what sustainable knowledge means. As in other transdisciplinary fields, sustainability sciences are dependent on how different stakeholders act, think, and interact in a knowledge society, conscious of their individual limitations but also of the potential evolution they create as a collective.

To be effective, both approaches must take into account that knowledge in sustainability is multidimensional scientifically, socially, and politically. This makes both interdisciplinarity and transdisciplinarity intrinsic to developing sustainability. The challenge of this is to undo our fascination with specialization and, at the same time, to rescue lost knowledge and feelings, reintegrating the various fields of knowledge, thereby enabling better understanding and problem solving. This implies treating science and technology as an intrinsic process to society that influences and is influenced by society. In this context, the classical view of science, supposedly neutral with regard to social and political values, is not something reasonable. Technological-scientific process does not exist on the margins of society. It is the society that gives practical and symbolic value to any knowledge and technologies. Due to its empirical, inter- and transdisciplinary nature, the sustainability sciences field represents well the intertwining of science, technology and society, requiring to consider their mutual relations.

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PART V

TRANSDISCIPLINARITY AND THE PROFESSIONS

CHAPTER 27

RELIGIOUS STUDIES AND RELIGIOUS PRACTICE

SARAH E. FREDERICKS

The academic study of religion has a diverse subject studied through multidisciplinary, interdisciplinary, and transdisciplinary methods. This multifaceted mode of scholarship is grounded in the diverse nature of religion itself as well as the long history of interaction between religious practice and religious studies.

27.1 Introduction

When discussing religious studies and the practice of religion, one of the first tasks is to clarify what "religion" is. Definitions of religion are frequently debated both in and outside of the academy. While many laypeople think of religion as requiring belief in a god or gods, many academics now recognize that emphasizing belief when trying to define religion distracts from traditions where following the law or rituals are paramount. Similarly, focusing on a god or gods, terms that in English often evoke personal images of a deity, may exclude a number of traditions, for example, Buddhism, that have no such idea. Furthermore, such a definition eschews the community structures and material cultures whose presence (or conspicuous absence in the sense of ascetic groups) is tightly bound to religious belief and practice.

Thus, many contemporary academics favor a description of religion based on a number of dimensions (e.g., doctrines, rituals, ethics, material culture, social organization) that may be more or less present in any particular religion (Smart 1996). Notably, such descriptions of religion fail to draw a hard line between what is and what is not religious, as political groups or particularly ardent groups of sports fans may also all share these characteristics, but the broadness of the definition enables scholars to explore the continuities between a wide variety of human phenomena including groups often deemed "secular." Such a dimensional analysis also keeps guard against privileging the characteristics of one's own religion above others as it provokes one to explore the whole phenomena.

In the context of this study of religion and interdisciplinarity, such expansive multifaceted descriptions of religion also point to the multidisciplinary, interdisciplinary, and transdisciplinary nature of religious studies as a field. Some scholars are experts in a subset of the

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various characteristics of religion and may use unique methodologies to study them even as all of the different specialists are studying religion. Ethicists for example, may construct ethical theories or make ethical judgments while studying religious ethics; anthropologists or sociologists may emphasize community structures, material cultures, and rituals as much as or more than beliefs in their surveys, interviews, and observations. Similarly, linguists, textual experts, archeologists, theologians, philosophers of religion, and art historians may have their own content and methodological emphases. Yet all may consider themselves religious studies scholars, serve in departments with each other, and to a greater or lesser extent, use each other's work to inform their own research and teaching.

To demonstrate the multidisciplinarity, interdisciplinarity, and transdisciplinarity of the study of religion, we should first look to the development of religious studies, the places of secularity and collaboration with religious practitioners in religious studies, and the ways ecumenical and interfaith activities draw on religious studies and parallel interdisciplinarity and modes of transdisciplinarity today. I emphasize the Western (European and North American) context, as this is where religious studies as an academic discipline arose. Contemporary examples of the interaction of religious studies and religious practice will focus on the American context because it is necessary to practically limit the examples, because this is my area of expertise, and because the study of religion in America has been influential on the broader discipline of religious studies.

27.2 Predisciplinary Religious History

Throughout most of human history what is now called "religion" was coterminous with culture. All sorts of actions were ritualized to connect people with each other, the broader world, and the transcendent in one overarching worldview. While shamans, priests, or other religious leaders may have had distinct access to religious knowledge or experience, it was typically understood to be unified with all other knowledge and was studied to develop their religious practice. Thus, the modern view of religious studies as a discipline distinct from both other disciplines and religious adherence is inapplicable to much of history.

Even when distinct academic disciplines arose, it was assumed that their content was connected. For instance, traditional Islamic scholarship was based on explicit metaphysical principles that formed the foundation of all thought (Nasr 1996). This schema linked areas of study including the religious "sciences" of Quranic exegesis, Hadith studies, and jurisprudence as well as other branches of thought including astronomy, alchemy, medicine, and mathematics. (The term "science" is used here in its medieval meaning of a form of knowledge and learning. It does not imply the experimental, law-based potentially reductionistic vision of science popular in the modern world.) One such principle is *al-mīzān* (balance). Use of this term across the sciences continually reminded scholars of their belief that all knowledge is interconnected even though the term had different connotations in various sciences. Some philosophical schools defined balance as (1) the way "consequences of human action are weighed in the next world," (2) "the necessity of leading a morally balanced life in this world," or (3) "the discernment that allows us to establish balance in all aspects of life" (Nasr 1996). It was also used as a physical term in studies of weights, mechanics, and hydrostatics or to indicate that the proper proportion of qualities of nature (hot, cold, moist, dry) was reached (Nasr 1996).

Moving ahead in time to the early modern period and traveling from the Middle East to western Europe, we see that religious ideas often shaped and were shaped by those of other disciples even though the early modern period is often understood as the time when academia was secularized. As John Hedley Brooke points out, many significant advances in early modern science explicitly used theological claims. For instance, after seeking a physical explanation of gravity, Isaac Newton eventually decided that God must be the source of all forces and periodically intervene to keep planets in their orbits (Brooke 1991). The move from allegoric and symbolic to more literal biblical interpretations during the sixteenth century Protestant reformation led natural philosophers to increasingly investigate the world literally— as a series of events that had integrity in and of themselves—not as symbols for something else. Scholars began to study biblical stories, such as the flood story, factually. According to Janet Browne, such research helped spark interest in species development and migration in the seventeenth and eighteenth centuries (Browne 1983).

Such interactions are not, however, limited to analytical realms of religious life. Religious practitioners have, since ancient times, also engaged with, developed, and used knowledge from a variety of disciplines for ritual purposes. Astronomers created calendars in part to determine the proper dates of religious rituals in ancient India, Mesopotamia, Central America, and Egypt. The arts, whether architecture, music, or visual arts, have also often been developed in order to serve religious purposes—to generate awe in sacred spaces, to remind people that everyday objects are sacred, to reinforce beliefs or educate an illiterate population.

Religious concepts, methods, and activities shaped and were shaped by other fields of thought, so stark delineations between the study of religion and other academic disciplines are anachronistic for much of history. Similarly, multi-, inter-, or transdisciplinarity, as defined by Julie Thompson Klein and other contemporary scholars, do not adequately describe the historical examples noted above, because the new terms imply intentional efforts to overcome a separation between the disciplines and between scholarship and religious practice that did not yet exist enough to require a recombination (Klein, this volume). Medieval Islamic scholars, for instance, did conceive of disciplines with distinct methods and subjects; however, insofar as these disciplines shared terms, a metaphysical foundation, and a commitment to a vision of the unity of knowledge established by God, they also transcended our modern bounds of disciplinarity. Instead, the above examples show that religious scholars and practitioners identified subjects of study that blur the contemporary bounds between scholarship and religious practice and rely on a number of bodies of knowledge and experience that we consider outside of religion today. Nevertheless, these interactions lie at the root of the multidisciplinary, interdisciplinary, and transdisciplinary nature of religious studies today.

27.3 Religiosity and Secularity in Religious Studies

With the rise of modernity, the study of religion as a distinct academic discipline disassociated from the practice of religion became an ideal as religious scholars came to adopt one implicit requirement of contemporary disciplines: that the discipline's knowledge is publically available to anyone who wishes to study it (Weibe 1999). In many disciplines this assumption is so strong that it is rarely discussed. In religious studies, however, it is contentious enough to receive explicit attention. Some scholars maintain that the full meaning of rituals and beliefs or the depth of religious experience can only be understood by believers, adherents, or devotees. Others claim that such privileged knowledge is not necessary to study religion and that it should have no place in the academy. This debate, sometimes framed as one between theology and the social scientific study of religion, has been the most contentious element of the development of religious studies and illustrates one way it is multidisciplinary.

The academic study of religion in the West grew out of faith-based endeavors. After all, for much of human history the people who studied religion were religious leaders—shamans, priests, legal experts, and monks. Most focused on their religion, with some study of the traditions from which they came or with which they interacted. Thus, Buddhists knew about Hinduism, and Jewish, Christian, and Muslims scholars in Medieval Spain studied together. Yet, until the Enlightenment, there was no significant study of religion as a scholarly endeavor divorced from the belief in and practice of a particular religion.

With the Enlightenment and rise of Cartesianism, some Western scholars tried to identify the "essence" of religion. Whether the essence was identified with morality (Immanuel Kant), "the feeling of absolute dependence" (Friedrich Schleiermacher), the "mysterium tremendum" (Rudolf Otto), or "ultimate concern" (Paul Tillich), essence theories persisted well into the twentieth century. Developmental, comparative, and phenomenological approaches arose as competitors to essence theories, yet all of these claims of a general theory of religion were typically grounded in Christianity and prioritized Christian concepts (Gill 1994). Indeed, this cultural context has often led scholars to ignore elements of religion not central to Christianity whether they are oral traditions, sacred land, or the belief in multiple or no deities. Such bias has made it difficult for scholars to understand religious diversity.

In the United States, the prioritization of particular, typically Christian, belief systems in academia was a sign of Christian, and often Protestant, dominance as well as a means for reinforcing this domination throughout society. Well into the nineteenth century, children learned to read using primers infused with Protestant ideals, and most institutions of higher learning in the United States were founded with religious goals (Gaustad & Schmidt 2002). Only in 1962 did the Supreme Court rule that prescribed prayer in public schools was unconstitutional. In 1963, the Court clarified the status of religion in school by separating the practice of religion through prayer or ritualized Bible reading (unconstitutional) from the study of religion (constitutional and encouraged to help children understand history and culture) (Gaustad & Schmidt 2002).

The prioritization of Protestant belief systems and rituals in US history has had implications well beyond education. Many Protestant habits have been adopted by non-Protestant religious groups in order to fit into US society. For example, the Native American Church was incorporated and so named in 1918 in order to gain legal protection for their religious rituals (Thompson 2005). Many Japanese-American Buddhists in the internment camps of World War II adopted new rituals (e.g., English, Christian-style hymns in new prayer books) to become more "American," that is, more Christian (Williams 2006).

While religious studies scholars are not solely responsible for such societal trends, limited knowledge about religious traditions other than one's own contributes to prejudice. Seeking to avoid these dangers and the scholarly bias that has come from religiously motivated studies of religion, scholars such as Sam Gill and Donald Weibe argue that religious studies should not require, support, or evaluate religious beliefs and practices. Anyone, they argue, should be able to arrive at the same conclusions when studying religion.

Weibe, like many social scientists of religion, draws on Max Müller's general goals for the study of religion, including impartiality and critical historical and comparative analysis. He also emphasizes the search for the truth through preexistent facts rather than through the creative development of ideas, as in philosophy and theology (Weibe 1999). William M. Newman's 1974 study of the first 25 years of the Society for the Scientific Study of Religion (SSSR) reveals that over time dialogue between "religious believers" and social scientists who study religion was deemphasized in favor of the social scientific study of religion (Newman 1974). Wiebe would applaud such trends. He writes:

> If the academic study of religion wishes to be taken seriously as a contributor to knowledge about our world, it will have to concede the boundaries set by the ideal of scientific knowledge that characterizes the university. It will have to recognize the limits of explanation and theory and be content to explain the subject-matter—and nothing more—rather than show itself a form of political or religious behavior (or an injunction to such action). (Weibe, 1999)

Similarly, Sam Gill sees the tendency of religious studies scholars to segregate by religion and the frequency with which they study their own religion as a step away from the academic study of religion. Instead, Gill advocates comparative work and the study of overarching religious questions such as what religion reveals about personhood. Thus, both Gill and Wiebe think that the discipline of religious studies should be a unified endeavor without sectarianism that focuses on explaining religious phenomena, not developing religious ideas (Weibe 1999).

In this view, there is room to investigate traditional religious subjects as well as emerging phenomena such as the growing number of people who describe themselves as "spiritual but not religious," a term that generally implies some commitment to deep meaning and values without dogmatism or rote rituals. Similarly, this paradigm allows the study of other human groups that have religious-like features such as civil religion (Smart 1996). Thus, it can advance the field as a scholarly enterprise while enabling new insights about human phenomena.

Yet Weibe draws too sharp of a line between "objective," "social scientific" studies of religion and the study of religion for religious reasons. Gill and Weibe's assumption that a narrow definition of a discipline is necessary and their overreliance on social-scientific guidelines for religious studies causes them to reject significant elements of the field such as the literary, theological, ethical, and philosophical and to overlook the blurring of objective, constructive, and advocacy-based approaches to religious studies that may arise out of a social scientific approach.

In recent decades, the academic study of religion in the United States has shifted toward the study of world religions and away from studying Christianity alone. Faith-based studies of religion are yielding to critical, constructive, comparative approaches involving a variety of methods from multiple disciplines, religions, and cultures. These moves encourage students to "examine and engage religious phenomena, including issues of ethical and social responsibility, from a perspective of cultural inquiry and analysis of both the other and the self" (Religion Major and Liberal Education Working Group 2007). Thus, they are more than an "objective" study of religion but less than indoctrination into a particular religious tradition.

For instance, many religious studies courses now examine a particular theme (journey, death, food, etc.) and culminate in a project in which students develop their own positions on the subject. A course on death and dying may finish with a student project to articulate their wishes for the end of their life and explain the meaning behind such choices. Such activities do not presume that students belong to any particular religious tradition, or even a religion at all, but rather enable students to explore questions of deep meaning and value regarding a common experience of humanity.

Outside of the classroom, religious studies scholars may interact with religious communities in a variety of ways beyond the historical relationship in which a scholar developed ideas for his or her own religious community. Anthropologists, historians, sociologists, and other social scientists may find their work being used by religious groups whether or not they meant for this to happen. For instance, the Pew Forum on Religion and Public Life's Religious Landscape Survey may help religious bodies understand their current or potential members (Pew Forum on Religion and Public Life, 2008). The report notes such facts as young Latter-Day Saints and Jehovah's Witnesses leaving their religions at greater rates than young people of other religions. This knowledge, combined with the growing numbers of people, especially the young, who claim no religious affiliation may lead religious groups to emphasize youth in their outreach ministries.

Transdisciplinary work often involves religion studies and other scholars, religious people, and nonreligious people working together to address problems facing communities. For example, the Commission on Racial Justice of the United Church of Christ (UCC) took a social scientific approach to chronicle the correlation between the location of toxic waste storage units and the racial composition of neighborhoods in the United States (Commission for Racial Justice United Church of Christ 1987). This work, while motivated by the UCC's concerns for justice and care for all people, was not framed as a religious document— indeed aside from noting the authorship of the study, religion was not mentioned in it. Yet the study's significance was felt far beyond the UCC community as it helped catalyze the environmental justice movement both as a social movement and as a field of academic study. Indeed, the environmental and civil rights movements are often transdisciplinary movements composed of scholars, including religious studies scholars, and religious and secular activists. Scholars have often helped articulate or uncover ethical or theological reasons to support the movement and provide historical and sociological support for the movement. Religious leaders, whether preachers, community organizers, musicians, or laypeople provide leadership, organizational knowledge, finances, and physical resources, often including a place to meet. Religious studies scholars also contribute to these movements by documenting their experiences so that the groups in question and others can learn from their experiences. For instance, Laurel Kearns's work on religious environmentalism, particularly lobbying in Congress to save the Endangered Species Act, has shown the types of coalitions that have been successful, information helpful for future religious or secular advocates (Kearns 1997).

Gill, Weibe, and others would most likely find such new forms of explicit or implicit collaboration between religious studies scholars and religious people troublesome, for it threatens to blur the line between pure objective research and religious practice and may spark memories of past proselytizing. Such research is a new chapter in religious studies scholarship that aims to illuminate religious themes and articulate ethics of religions for use by religious activists in the tradition in question, or to foster ecumenical or interfaith or religious–secular alliances as people seek to understand their neighbors, potential collaborative partners, or opponents better. This collaborative work, however, is a form of transdisciplinarity—when scholarship helps address questions of the broader public and is put to use by them. When such partnerships are not just about scholars or religious leaders foisting their ideas on others, but are actually about working together to solve problems, then we see more of a transdisciplinary model rather than old models of dominance. Yet the debate over whether religious studies should be theological, social scientific, or a new critical, constructive, intercultural, and maybe transdisciplinary method of inquiry is unlikely to be resolved in the near future, given the serious concerns many scholars have about collaboration with religious people. This ongoing diversity within the field of religious studies demonstrates another way in which religious studies is inherently multidisciplinary with respect to method and aims.

27.4 Interfaith and Ecumenical Parallels with Multidisciplinary, Interdisciplinary, and Transdisciplinary Work

Within the realm of religious practice, patterns of engagement and blurring boundaries found in the ecumenical and interfaith movements parallel interdisciplinarity in the academic world. These activities between different denominations of one tradition (ecumenical) or between different religious traditions (interfaith) aim to develop rigorous concepts of religious similarities and differences, promote peace and other social goals, and encourage proper relationships between religions. Ecumenical work may also advocate unity in the religion at large and may lead to mergers or blurred boundaries between denominations. Several types of inter- and intrareligious activity illustrates these trends: ecumenical organizations involving a wide number of religions (the Parliament of the World's Religions) or denominations (the World Council of Churches); interfaith movements arising out of conflict (Post-Holocaust Jewish-Christian dialogues or Islamic-Christian dialogues after 9-11), curiosity (Buddhist-Christian study in the United States), or concern about social problems (interfaith environmental movements).

Many parallels exist between these ecumenical and interfaith activities and interdisciplinary work. First, there are similarities between the structure of a denomination or religion and a discipline. Like disciplines, religious groups have some defined subject (e.g., the Ultimate, the human condition, myths), rely on epistemological, ontological, and metaphysical presuppositions, and have favored methods. These elements change over time to meet the needs of their religious communities as they interact with similar segments of other religious traditions. Despite differences in subject, presuppositions, and method, people involved in ecumenical or interfaith movements work across religious boundaries to address questions unsolvable by any one tradition: How do and should theologies, rituals, ethics, and histories relate? How should people within a tradition conceive of and relate to others? How can religions address social problems together? As ecumenical and interfaith activities rely on resources of various religious groups to address these issues, they are, in a sense, involved in interdisciplinary work. All of the challenges of interdisciplinarity arise here as well: the communication barriers between groups with different terms, methods, and presuppositions; the suspicion and distrust of groups different from one's own; and the potential for one group to dominate the activity.

Mircea Eliade warns that as much as other disciplines can aid understanding of religion, they cannot fully describe religion because they do not have the terms to appreciate and understand the sacred, thus the study of religion is a specialized field (Eliade 1996). Extending his argument, completely subsuming ecumenical and interfaith activities under the heading of interdisciplinarity will threaten to impoverish our understanding of religious activity. Certainly religious activity and the activity of academic disciplines have much in common, but the scope of a discipline is much narrower than the scope of religious worldviews. Disciplines, especially in our modern world, focus on narrow segments of or limited approaches to reality, while religion typically involves ideas about the human condition, ultimate reality, and the relationship of these to the world. A discipline may have a code of ethics, but its norms focus on behavior related to the discipline and are not sufficient to guide one's entire life, whereas religious norms typically aim to guide an adherent's entire life. These contrasts between disciplines and religions are just a few indications that religions are deeper and wider and involve more commitment than disciplines. Thus, if our understanding of ecumenical and interfaith interactions were reduced to interdisciplinarity, we would miss significant facets of these movements. It would be better to think of ecumenical and interfaith initiatives as a combination of the intellectual endeavors of interdisciplinarity and the engagement of communities of transdisciplinarity.

Despite the dangers of limiting our knowledge of religion by overusing the language of interdisciplinarity, using its various terms may help identify and understand the various ways religious groups interact, since religious studies has not defined terms for all of the types of relationships and goals of inter- and intrareligious dialogue and action.

The first major modern interfaith endeavor was the 1893 Parliament of World's Religions, held in Chicago. A part of the cultural counterpart to the technical-focused World Columbian Exposition, the Parliament aimed to promote cross-cultural understanding through religions. The Parliament was dominated by Christians both in sheer numbers and in terms of groups underrepresented (Africans, South Americans, Indigenous traditions), by the groups not invited (Mormons, African Americans, Native Americans), and those groups not present (Muslims, Sikhs, and Tibetan Buddhists). The Parliament was successful insofar as it enabled Asian religions such as Hinduism and Buddhism to formally introduce themselves to the West and as it promoted understanding among Christians (Kuschel 1993). The Parliament of 1893 is a prime example of multidisciplinary encounter; religious people wanted to learn about each other but did not aim to collaborate or integrate their ideas.

The centennial celebration of the Parliament in 1993 had a different aim: to articulate the global ethics already found in the world's religions. It expressly did not seek to establish a universal religion or obliterate the religious ethics of individual religious tradition. Rather it sought to identify common ethics (the golden rule; do not lie, steal, kill, or commit sexual immorality) necessary for a world with increasingly global structures of economics, politics, and society. With much more diversity than the first Parliament—with 6,500 representatives from nearly all world religions (evangelical and fundamentalist Christians were notably absent)—it has been praised for its movement toward a global ethic even as elements of its process and content have been criticized. This event illustrates one facet of much interreligious and ecumenical work: the discovery of existing commonalities between groups that can be the basis of future study, collaboration, and peace even as participants recognize and affirm the differences between their traditions.

The World Council of Churches (WCC), organized in 1948, has exhibited similar trends within Christianity. It is the largest ecumenical organization within Christianity, with over 300 member churches comprising over 500 million individual members from over 120 countries. "Church" is often equated with a local congregation, but can also indicate an organizational body that unites many individual congregations, often according to theological, ritual, and regional or national ties. Churches in the WCC include, among others, many Orthodox churches, Anglicans, and Protestant churches including Lutheran, Methodist, and Baptist churches.

The WCC aims to recognize and reinforce the significant common beliefs among Christians through worship and action. It does not intend to be a monolithic church body where all differences are wiped away. The WCC's decisions are not binding on its members. Rather, its activities are supposed to enable debate and prophesy through which members will be challenged to live lives of faith and service. The WCC's activities often involve theological, ritual, and ethical innovations, as experimentation is possible within its nonbinding format. Since these actions aim to resolve religious problems about ecumenical worship and social problems about war, economics, racism, environmental degradation, and human rights while transcending denominational boundaries without seeking to obliterate all difference, the WCC members are operating in a parallel to elements of transdisciplinarity and multidisciplinarity.

Cooperative study and reconciliation is not, however, limited to ecumenical discussions. For example, the scholarly study of and community reflection on Jewish–Christian relationships has grown considerably since World War II. Many factors led to this interfaith work, including the horrors of the Holocaust, the establishment of the State of Israel, the ecumenical movement, the Second Vatican Council, and enlightenment visions of human dignity and equality (Kessler 2006).

Insofar as these dialogues aim to articulate constructive new relationships, they engage in activity similar to critical interdisciplinarians who study the relationship of knowledge between fields. As Jews and Christians collaborate to promote peace, a goal many argue cannot be achieved by either group alone, their activities parallel instrumental interdisciplinarity. Yet interdisciplinarity, whether critical or instrumental, does not quite fit this situation, because each religion intends to remain distinct even as they learn from each other. Thus, there will be barriers to the amount of integration either group is willing to entertain.

Muslims and Christians have recently begun similar dialogues. On September 13, 2006, Pope Benedict XVI gave an address that was widely regarded as implying that Islam was violent and immoral. In the wake of this address, Islamic leaders and scholars wrote an open letter to the pope to discuss their faith and promote understanding of Islam. The next year 138 Muslim leaders from all branches of Islam and all major Islamic nations and regions released *A Common Word between Us and You*. This document brought Muslims together in a way not experienced since the time of the Prophet Mohammed. Through this document, and a series of conferences in 2008 with hundreds of Catholics, Anglicans, and Protestants in turn, Muslim leaders hoped to promote understanding of what the faiths share and to promote peace. Importantly, participants in the conferences did not intend to (1) convert each other, (2) make the other adopt ideas of their own theology, or (3) reduce the two religions to a common denominator or new religion. Rather, the document looked to the sacred texts of the Bible and Quran to discover what Christianity and Islam have in common in order to begin to work for peace (Volf 2009).

In contrast, Buddhist–Christian dialogue in the United States has primarily been an academic affair, in which scholars expert in each of these traditions have studied the major ideas of Buddhism and Christianity in a comparative fashion (Lai & Von Brück 2001). (Buddhist–Christian dialogue in countries with significant Buddhist populations has spent more time on the social implications of contact between the religions and has involved religious communities and scholars.) Studies cover a wide range of topics, but issues of ultimate reality; meditation, contemplation, and prayer; suffering; and ethics have been most popular, as is demonstrated in the *Journal for Buddhist–Christian Studies.* "Multidisciplinarity" describes some of these endeavors, as scholars study the same phenomenon sequentially using different theories or use the same theory to explore different phenomenon. Buddhist–Christian dialogue, however, is more often interdisciplinary or transdisciplinary, as it aims to integrate insights from various religious traditions and academic disciplines. Though most of the comparative work between Buddhism and Christianity in North America has occurred within academic circles rather than in religious communities, this does not mean there is a clear distinction between academics and religious practice in Buddhist–Christian studies. Many scholars engaged in this dialogue are themselves Buddhists, Christians, or adherents of some beliefs and practices from each system. These scholars engage in dialogue in part to develop their own religious ideas, a form of transdisciplinary endeavor.

People of different religions also come together to resolve pressing social issues that do not directly stem from their religious differences, a type of collaboration that can be classified as instrumental interdisciplinarity as groups rely on their various methods and beliefs to reach a common goal. For example, various faith communities collaborate to promote environmental protection. The Evangelical Environmental Network and the National Religious Partnership for the Environment, a group of mainline Protestants, Catholics, and Jews, campaigned to save the Endangered Species Act in the 104th Congress (Kearns 1997). Interfaith Power and Light organizations located in most states also educate religious communities about how to simultaneously save energy, money, and the planet; band together to purchase cheaper energy; and provide a support network to help achieve such changes.

Though interfaith and ecumenical activities should be distinguished from interdisciplinarity because of their connection to religious belief and practice, there are enough parallels between them that scholars engaged in interdisciplinary endeavors can learn from these activities. First, they could learn of the dangers, both to understanding and to interpersonal relationships, of evaluating other disciplines with the criteria of one's own and calling it a dialogue. One does not need to look far to find prejudicial (intentional or inadvertent) descriptions of religious traditions unfamiliar to the adherent or scholar. For instance, Christians have long ignored the importance of land to Native Americans. Second, ecumenical and interfaith activities may teach interdisciplinarians about forging terms that resonate with multiple perspectives to avoid privileging or ignoring one viewpoint. For example, "Ultimate Realities" or "Ultimate Reality" are terms used to avoid the limitations of "God" language. Third, interdisciplinarians could learn something about how to link communities that not only have different methods, assumptions, and subjects but also experience deep distrust or animosity toward the other based on centuries of prejudice, persecution, and power imbalances. Working to resolve practical problems about the environment, peace, and other social issues can often be a starting point to deeper collaboration. Academics may find that working to address community issues can build bridges between hostile disciplines. For all of these reasons, interdisciplinarians would do well to learn from the experience of the ecumenical and interfaith movements.

27.5 Conclusion

Though "multidisciplinarity," "interdisciplinarity," and "transdisciplinarity" should not replace terms like "ecumenism" and "interfaith," something like the integrated results of interdisciplinarity and transdisciplinarity has long been a facet of religious study and practice. Religion is a subject that predates the rise of modern disciplines and has often been seen as connected to all modes of thought and experience. Indeed, scholars have often connected what we today divide into the "secular" and "religious." We see this inter- and transdisciplinarity today as religious practitioners use ideas and methods from art, psychology, history, languages, and the sciences. As scholars study these diverse phenomena they often form subdisciplines of the academic study of religion, which may relate to each other or to other disciplines in multi- or interdisciplinary ways. Of course, this diversity has and does lead to quarrels about the proper ways to study religion. The benefits of such diverse modes of study and practice, if done well, outweigh the costs. Multifaceted scholarship about religion enables scholars to acknowledge the complexities of religion itself. Transdisciplinary religious practice keeps religion relevant to the intellectual and practical concerns of its people. In a fitting move given the history of religious studies, religious studies scholars are forging a new path between the extremes of objectivity and proselytism to encourage description and critical reflection so that religious studies becomes an openly interdisciplinary discipline and so religious practitioners can benefit from such knowledge and experience.

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CHAPTER 28

INTERDISCIPLINARITY IN THE FIELDS OF LAW, JUSTICE, AND CRIMINOLOGY

STUART HENRY

In an effort to transcend the Kantian tradition whereby subdisciplines of the social sciences know more and more about less and less, and where academics increasingly talk only to specialized, divided, and isolated colleagues, in the late twentieth century, scholars in law, justice, and criminology began to talk beyond their own disciplines. They did so by integrating the insights from a divergent range of disciplines and subdisciplines, a process which has taken several forms. In this overview I first review the development of interdisciplinary thinking in law, which has typically taken a hybridization approach to knowledge integration. I then turn to the development of interdisciplinary thinking in criminology, which has been much more thoroughly articulated to the point of forming its own subfield called integrative criminology.

28.1 Interdisciplinarity in Law: The Hybridization Approach

Law and legal studies illustrate one approach to interdisciplinarity whereby two disciplines join together to form a hybrid, such that concepts, theories, and applications emerge from the nexus of the two disciplinary traditions. Examples of this approach are found in its interdisciplinary subfields, which include law and psychology, law and society, anthropology of law, economics and law, feminism and law, critical legal studies, masculinities and law, and semiotics and law. Not only are there professional associations for these hybrid disciplines but also there are journals (e.g., *Law and Society Review, Journal of Law and Society, Law and Social Inquiry*).

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Interdisciplinary approaches to law have much to do with the idea that law exists in a sociopolitical context, rather than being an independent system of rules, as legal formalists and legal positivists had argued. The lines between the legal doctrine of formal law and other social orders become blurred once it is acknowledged that law is just one form of social control, each shaped by culture, social structure, custom, tradition, and a variety of reciprocal obligations and duties that exercise control over human behavior. This legal pluralist perspective has resonance with the sociologist Eugen Ehrlich's concept of "living law," Oliver Wendell Holmes' sociological jurisprudence, and Karl Llewellyn and Jerome Frank's legal realism, each of which also bring attention to the sociopolitical influences that shape law and its application. The importance of social context was also at heart of the critical legal studies movement's charge that legal formalism's claim of the independence and neutrality of law was a "big lie," as law and its application are shaped by politics however these cases might subsequently be rationalized by judges' decisions.

It is in law's application that we see its interdisciplinary hybridization in for example, the "fruitful marriage" between international relations and international law (Dunoff & Pollack 2013; Jo 2014), law and medical ethics (Müller et al. 1997), law and social work (Duraj 1982), and family law (Babb 1997). Under the umbrella of clinical legal education, interdisciplinarity becomes thematic when law is used as an instrument to bring about social justice (Voyvodic & Medcalf 2004). In family law, this interdisciplinary awareness can also embody the concept of law as a therapeutic agent, whereby courts take an ecological and therapeutic approach to the well-being of families seen as embedded in neighborhoods and communities: "An interdisciplinary paradigm for family law jurisprudence that applies the ecology of human development perspective and notions of therapeutic jurisprudence can ensure that family law decision-makers and the courts are a source of strength and support for the continued and enhanced functioning of America's families" (Babb 1997, p. 775).

The rationale for such interfaces between law and other disciplines is well illustrated by intellectual property law, which "now trenches so deeply on issues of economics, culture, health, commerce, creativity, and intellectual freedom, it is no surprise that there is also a burgeoning literature on intellectual property issues that comes, not just from legal academics or lawyers, but from those trained in other disciplines" (Scassa et al. 2014, p. 1).

However, the role of interdisciplinary legal education has been the subject of some debate. This revolves around whether or not (1) interdisciplinary knowledge enhances a practicing lawyers' effectiveness in arguing cases and (2) whether the creative possibilities for problem solving that interdisciplinary collaboration provides (Weinstein 1999) is worth the wider scope of knowledge necessary to effectively practice law. Since the 1980s, many law schools have moved beyond the "trade school" and even transcended the "professional school" approach to legal education.

One of the ways law interconnects with other disciplines is through their subdisciplines, such as law and anthropology, law and politics, law and economics, and law and sociology. Foundational to the interdisciplinary approach to legal education is the relationship between philosophy and law, which was early on embodied into law, notably at the University of Chicago's School of Law and Northwestern University Law School. A key issue for interdisciplinary legal education is whether or not law schools should engage their students in multiple social science and humanities disciplines beyond their focus on legal doctrine. A related issue is whether law faculty are hired with only practitioner experience (trade school approach), or are hired to conduct research (professional law school approach) or whether they are also required to have a disciplinary-based PhD and a law degree (interdisciplinary approach). Important too is the extent to which law schools offer joint programs such as law and social work, law and business, law and public administration (for a brief overview of these issues with interdisciplinary legal education, see Solum 2008).

28.2 Interdisciplinarity in Criminology: From Multidisciplinarity to Transdisciplinarity

Criminology illustrates a more systematic and substantial development in its approach to interdisciplinarity, which is rooted in a multiparadigmatic view that looks at social phenomena from different perspectives or lenses. For example, criminology's theoretical knowledge base was seen as deriving from its multiple constituent disciplines, which include (1) philosophy, (2) economics, (3) biology, (4) psychiatry, (5) psychology, (6) social psychology, (7) sociology, (8) geography, (9) Marxism, (10) feminism, (11) postmodernism, (12) critical cultural studies, and (13) quantum physics (see Einstadter & Henry 2006).

While mainstream criminologists developed the field's knowledge base from its constitutive disciplines, criminology, criminal justice, victimology, and justice studies tended to embody an applied form of interdisciplinary integration whereby distillations of these discipline-related theories were applied in attempts to improve the criminal justice system's response to the realities of crime and law-breaking. These policy applications were implemented through different techniques of crime control informed by a variety of correctional ideologies (Einstadter & Henry 2006). It was not until the twenty-first century that "criminal justice" developed a body of theoretical models of justice with up to eight different theoretical paradigms applied to explain different approaches to justice (Kraska & Brent 2011).

While multidisciplinary or multiparadigmatic approaches acknowledge the range of disciplinary perspectives, are more inclusive, and provide a kaleidoscope of insights valuable for comparative analysis, they fail to integrate knowledge across perspectives. They also fail to integrate core concepts and theories into one corpus of knowledge about crime. Thus, in 1979 criminology embarked on a more rigorous approach to integration of disciplinary knowledge. This field began to explicitly integrate knowledge from the various discipline-informed theories and with knowledge integration as its object. Thus, Margaret Farnworth defined theoretical integration in criminology as "the combination of two or more pre-existing theories, selected on the basis of their perceived commonalities, into a single reformulated theoretical model with greater comprehensiveness and explanatory value than any one of its component theories" (Farnworth 1989, p. 95). The criminological definition of interdisciplinary theory was remarkably similar to the one subsequently developed for interdisciplinarity in general, by Klein and Newell (1997).

These foundational concepts of interdisciplinary integration in criminology demonstrate not only the added value of integration but also why interdisciplinarians need to take note of the interdisciplinary thinking in other fields and indeed in the disciplines themselves (Jacobs 2013). Critical, then, is an interdisciplinarity of interdisciplinarity, which might be one way of conceiving of transdisciplinarity, but not the only way (Nicolescu 2002).

In the field of criminology, interdisciplinary thinking spans a 30-year history, starting with work by Elliott et al. (1979), followed by significant contributions from Colvin and Pauly (1983), Messner et al. (1989), and Barak (1998). Supporters of interdisciplinary integration argue that those engaging in integration in criminology do so for a variety of reasons, including (1) a desire to arrive at central anchoring notions in theory, (2) to provide coherence to a bewildering array of fragmented theories, (3) to achieve comprehensiveness and completeness, (4) to advance scientific progress, (5) to synthesize causation and social control, and (6) to reduce the number of theories in the field (Barak 1998; Einstadter & Henry 2006, p. 309). Critics, in contrast, argue that it is more productive to have both the depth of disciplinary inquiry and the contrast in explanations that correspond to different and nuanced problems of the complexities of crime. These critics celebrate "theory competition" and even "competitive isolation," over theoretical integration, which produces "theoretical confusion," or "theoretical chaos" (Einstadter & Henry 2006, pp. 319–320), if not "theoretical mush." Indeed, it has been noted that criminology shows a "considerable indifference and healthy skepticism toward theoretical integration" (Einstadter & Henry 2006, p. 309). This skepticism has led to serious consideration of a number of challenges faced by interdisciplinary integration which I consider next.

28.3 Issues of Integration

For those criminologists who have adopted an interdisciplinary approach, several issues have emerged that have informed interdisciplinary thinking in general. These include (1) false assumptions about discipline-based theories as nonintegrative; (2) conceptual integration; (3) propositional integration; (4) causal integration; and (5) cross-level integration. In the following section I summarize each of these issues that draw on our previous work (see Einstadter & Henry 2006; Henry & Bracy 2012).

28.3.1 Assumptions That Discipline-Based Theories Are Nonintegrative

Academic disciplines have been depicted as closed, static, autopoietic systems of knowledge policed by their formally trained members who control their content, defend their boundaries, and are in danger of becoming fossilized. Although disciplines have been described as "academic tribes," rather than engaging in tribal warfare disciplines engage in academic avoidance, tending "to talk past each other" (Repko 2008, p. 31).

Jacobs (2013), however, disputes this view, claiming that disciplines are not policed, "are not silos" but open, vibrant, and dynamic fields of knowledge, with "fuzzy boundaries." He says disciplines compete with each other over definitions, concepts, theories, and research methods in order to solve disciplinary problems and develop the intrinsic knowledge of their fields or pursue "knowledge for its own sake" (Jacobs 2013, pp. 34–35, 39). He claims that through their internal departmental organization, disciplines gain autonomy, strength, resources, new members, and students. Jacobs says that diversification through subdivisions within disciplines, is one way that disciplines maintain their creativity and promote the development of applied fields and professional studies that eventually grow into competitors in the marketplace for students. Thus diversification also moves the discipline beyond its narrow but deep focus while also providing a vehicle for innovation and interdisciplinary dialogue. Indeed, he claims that the accumulated disciplinary specialization "raises questions about whether an emphasis on interdisciplinarity can, in fact, integrate knowledge" (Jacobs 2013, p. 53).

With regard to integration within criminology, the question becomes whether an intellectual synthesis of knowledge across disciplinary boundaries is possible. This depends on what one is integrating.

28.3.2 Conceptual Integration

Conceptual integration involves, first, identifying relevant concepts from different disciplines and, second, "reconciling these through redefinition, extension, organization or transformation" (Henry & Bracy 2012, p. 263). Such "textual integration" involves finding concepts "that have similar meanings in different theories and merging them into a common language" (Einstadter & Henry 2006, p. 316). Abstractly, theories are generally built up from concepts, or kernels of ideas, that theorists then link together into explanations for events or phenomena. In practice, many theories start with others' explanations that are modified by creating concepts to fit, or by borrowing concepts from other theories. As Jacobs describes it, "disciplines can be thought of as sharing a dormitory space whereby they raid each other's closets and borrow each other's clothes" (Jacobs 2013, p. 37).

Conceptual integration, then, involves identifying common elements among the separate disciplinary components of theory and either expanding the definition or stretching the definition to accommodate the similarities in meanings of related concepts and acknowledging where differences exist and reflecting on whether the differences are complementary or contradictory. As we have argued elsewhere, "Merging concepts is not the simple task of focusing on similarities and ignoring differences. Rather, it entails figuring out how to utilize those similarities in a way that retains the integrity of the original concept" (Henry & Bracy 2012, p. 264).

Conceptual integration in criminology and criminal justice, also called "conceptual absorption" or "conceptual blending," takes concepts from at least two separate discipline-based theories and merges them into one transcendent concept. As indicated, conceptual integration may distort, even transform, a disciplinary concept by creating a new or blended concept.

An illustration of conceptual integration or "conceptual convergence" is found in the work of Ribaud and Eisner (2010, p. 300) who take core concepts of neutralization theory derived from sociology, moral disengagement theory from psychology's social learning theory, and self-serving cognitive distortions that stem from cognitive psychology, to form an integrated moral neutralization theory of crime causation with its own transcendent concepts. The basic idea of these theories is that words and phrases can be used to reconcile moral dissonance stemming from knowledge of the rules and knowledge that actions cause harms to others. Although scholars had noticed the seeming overlap between neutralization theory and moral disengagement theory, Ribaud and Eisner systematically and explicitly analyzed the meaning of each concept and determined that these were consistently convergent in measuring the same cognitive processes. They went on to further integrate moral neutralization, which can be seen as a microlevel process theory, into a wider or more macrolevel theoretical frame of crime causation. However, as we shall see below, the choice of which theories to integrate or which levels of analysis to draw from can produce a diversity of integrated frameworks.

28.3.3 Propositional Integration

Theoretical propositions are statements about the relationship between two or more variables, or among a specific set of variables. Propositional integration refers to "combining propositions from theories or placing them in some causal order or sequence" (Lanier & Henry 2004, p.343). Propositional integration is more complex than conceptual integration because the propositions have to be meaningfully linked rather than simply combined (Paternoster & Bachman 2001, p. 307). For example, Robinson (2004, pp. x–xi) advocates building integrative theory in criminology by examining the tested contribution made by "risk factors" derived from each discipline, and showing how they can interact cumulatively to increase the propensity for a person to commit crime (Robinson 2004, p. 271). The challenge to interdisciplinary integration is that propositional integration can result in an exponential increase in the number of variables, making theory testing complex and requiring large sample sizes.

There are three main ways that propositions can be integrated: (1) end-to-end or "sequential integration," which implies a sequential causal order; (2) side-by-side or "horizontal integration," which implies overlapping influences; or (3) up-and-down or "vertical integration," which "refers to identifying a level of abstraction or generality that encompasses much of the conceptualization of the constituent theories" (Messner et al. 1989, p. 5).

28.3.3.1 Sequential Integration

Sequential integration links the immediate or proximal cause of crime to a more distant cause of crime, and then links that to an even more distant cause. For example, an incident of school violence might be the outcome of the following process of sequential causes over time. Biological deficits at birth may lead to low IQ, which leads to learning disabilities in early childhood, which may lead to an inability to follow social norms, which may lead to poor academic performance, then to group and institutional exclusion, deviance and minor rule breaking, to school suspension and eventually expulsion, which produces reduced self-esteem and alienation, which generates anger and hostility. One result of this sequence of emotional distress is the formation of affiliations with similarly alienated peers, which can lead to delinquent peer or gang formation, which can lead to law violation, bullying in the school, and other forms of school violence.

In this illustration, school violence is explained by a series of theoretical propositions drawn from disciplinary informed theories: subcultural theory, learning theory, neutralization theory, cognitive theory, and biological or genetic theory. No one discipline completely explains the whole sequence resulting in the incidence of school violence, but linked end-to-end the integrated propositions from the different theories informed by their different disciplines provides a more comprehensive explanation.

28.3.3.2 Horizontal Integration

Horizontal integration explains different kinds of crime or different types of criminal. In horizontal integration, the overall explanation of a phenomenon is simply a combination of the separate explanations (Paternoster & Bachman 2001, p. 308). So, one disciplinary-based theory, such as economically rooted rational choice theory may explain corporate fraud, while another, such as sociologically based neutralization theory, may explain occupational crime, and so on (Moffitt 1993). Together the collection of disciplinarily informed theories explains a variety of crimes, and it is also possible that two or more theories may explain the same type of crime but different types of offender. For example, Moffitt's (1993) life course theory distinguishes between adolescent limited offenders who have a pattern of extreme antisocial behavior during adolescence, but undergo maturational reform by early adulthood after which they cease offending, and adolescent-persistent offenders who exhibit criminal activity across their life course. She argues that a different causal explanation is needed to explain the two types of offender, even though they may commit the same kinds of crimes.

Horizontal integration then addresses the "scope of theoretical explanation and whether the integration is intended to explain crime in general or a specific type of crime, or whether it is intended to explain a specific kind of motivation across a range of different crimes" (Einstadter & Henry 2006, p. 318).

28.3.3.3 Vertical Integration

Vertical integration attempts to explain crime by generalizing from a range of constitutive discipline-informed theoretical explanations. Integration involves creating a synthetic theory of sufficient generality that incorporates multiple propositions, each of which explains a part of the process that is the crime. The difference between this and propositional integration is that each of the explanations is necessary in explaining the crime, but that none alone is sufficient (Henry & Bracy 2012). Consider again the example of school violence, particularly rampage shooting. Several different theories offer explanations for why some students commit mass homicide in schools. Control theory, for example, has as a key concept parental attachment, which is inversely related to violence in conventional family settings. Low parental attachment combined with other elements, such as low commitment to convention and lack of involvement in conventional activities, can result in a student doing poorly in school and reacting to that outcome by blaming the school or the educational system as unfair or unjust. Conflict theory, developmental theory, and life course theory argue that family conflict can arise from a variety of internal family dynamics or external societal pressures and can produce conflict-ridden families and abuse, physical or sexual, of children. This can result in low self-esteem or acting out, depending on the internal cognitive thinking patterns; acting out can be directed at the perceived injustices of the school system. Social learning theory explains that a child in an abusive home may model their behavior on their parents' behavior, especially seeing problems confronted by rage, anger, and violence rather than by reasoned problem solving. This can also be reinforced through the self-selection of violent imagery through violent video games, violent music, and violent movies. These scripts and the Internet can provide knowledge about weapons and their force, and contribute to plans of attack at their school, as the student takes out his aggression on its victimizers, symbolizing the oppressors at home and the injustice of society seen as represented by the school and educational system.

Vertical integrated theory would argue that none of these theoretical propositions alone explains rampage school shooting, but taken together they show how such mass homicide attacks can be the codetermined outcome from the different propositions acting in the same direction. This is not because one factor causes the other to occur, as in sequential integration, but rather because relations in one social sphere such as the family are part of the relations in another social sphere, the school, and relations with the media and popular culture are part of the relations of school and family. Thus, when changes occur in one sphere these simultaneously change the qualities of the other sphere (imagine a Venn diagram). When changes build over time and move in one direction that accumulates small incidences of violence, the outcome can be an explosion of violence that has been referred to as a rampage shooting (Henry & Bracy 2012).

28.3.4 Causal Integration

It is important to consider how causation is integrated, as has been implied in each of the previous sections. As we have argued (Henry & Bracy 2012), to simplify matters, four kinds of causality can be distinguished: (1) linear causality, which takes the form of a sequential chain of events; (2) multiple causality, which sees the phenomenon to be explained as the outcome of several different independent causes or a combination of interdependent causes (but see 4 below); (3) interactive causality, in which, in turn, the effects of one event influence its cause(s), which then influence(s) the event; and (4) dialectical or reciprocal causality, in which causes and events are not discrete entities but are overlapping and interrelated, each being codetermined and each codetermining the other (see Einstadter & Henry 2006). "In interactive causality one cause produces an effect, which subsequently acts back on the original cause and affects it in an interactive cycle. In dialectical/reciprocal causality causes and events are intertwined such that each is a part of the other," as was illustrated above in the case of rampage school shootings (Henry & Bracy 2012, pp. 267–268).

A clear example of dialectical or reciprocal causality is found within the integrative theory of the sociology of law. In conceiving of the relationship between "law" and "society," integrative theorists posit that these are not separate entities. Indeed they are not even unitary entities. Society is made up of a multiplicity of social orders that operate at a range of different levels: from the group level to the organizational level to the societal and even to the global level. Likewise, law is not one body of rules and sanctions but is constituted by and through these different social orders. Law then is plural and integral to society. Thus over time, small changes in one order and its law change other orders, such that the whole interrelationship is dynamic and constantly changing, iteratively.

28.3.5 Cross-Level Integration

Finally, given that disciplinary-based theories address different levels of analysis across the spectrum of social relations ranging from micro-, to meso-, to macrolevel, we need to consider whether an integrated theory should occur within a specific level of integration (e.g., micro- to micro-) or whether integration should occur across different levels (e.g., micro- to macro-), which is called "cross-level integration" (Messner et al. 1989, pp. 5–6, 13–14).

In one sense, the number of levels integrated in cross-level integration depends on the overall objective of integration. If the goal of integration is to explore a unique relationship, such as that between individual pursuit of violent music or gaming videos, and the corporate interest in maximizing media sales through sensational and violent charters or themes, then perhaps it is only necessary to cross the micro–macro level of analysis (say, linking psychological development and cognitive processes to perception, motives, and meaning as this relates to macro-level theories of capitalist expansion of choice and opportunity). An example of cross-level (macro–micro) integration in criminology is Colvin and Pauly's (1983) attempt to combine Marxist, conflict, and strain (macrolevel) with subculture, social learning, and social control (microlevel) theories. However, if comprehensiveness of causal factors is the goal, because of policy creation and implementation to address a complex social problem such as school violence, then all three levels need to be addressed simultaneously in what has been called "multilevel" integration (Paternoster & Bachman 2001, p. 305).

For simplicity, three integrational levels can be distinguished: "(1) kinds of people, their human agency, and their interactive social processes (micro); (2) kinds of organization, their collective agency, and their organizational processes (meso); and (3) kinds of culture, structure, and context (macro)" (Einstadter & Henry 2006, p. 319). It is important to note that Uri Bronfenbrenner's (1979) integrated systems theory of child development includes two more: exolevel, which relates interactive proximate contexts to distal contexts, and chronolevel, which considers the effects of patterns of events across time and space that can occur at each level and as a result of the interaction between levels.

Without an explicit awareness that multilevel interactions occur, interdisciplinarians might unwittingly integrate a range of theories at one level, for example, the microlevel. Indeed, in a meta-analysis of integrative theory in criminology 16 different integrated theories were identified (Lanier & Henry 2010, pp. 385–389). Interestingly, two-thirds of these integrated theories drew on microlevel theories compared with one-third that drew on macrolevel theories. In short, integration of discipline-based theories in criminology has typically been biased toward same-level rather than cross-level analyses, which might be because, "a focus on the more proximal as opposed to distal factors . . . combined with a careful analysis of risk and protective factors at the school and student levels, is a more feasible alternative for consideration by educators" (Sprague, Close & Walker 2014, p. 158). In addition, the tendency for theorists to focus on the more proximal as opposed to distal causes in the case of school violence, for example, is because of "our society's ideological position that the problems of school violence stem mainly from individuals, specifically the students and their parents, rather than the system, the community, or the wider culture or social structure" (Muschert et al. 2014, p. 224).

28.4 Evaluation: Disintegration of Integrated Theory

As we have seen, theoretical integration in law, justice, and criminology attempts a meta-level analysis ostensibly to transcend the limits of competition between multiple competing individual discipline-based theories. Do the results of integration warrant the effort? The results may be that the original goal of reducing the number of competitive theories is replaced by competition between different types of integrative theory. Just as disciplines invest time and energy in developing their theoretical contributions and advocating that these are either superior or complementary to others' theories, integrationists argue and advocate for their particular integrative model as the best combination of theories. This happens for a variety of reasons.

Since integrative theorists may use different criteria to construct their comprehensive approach, "what emerges is integrational chaos" (Einstadter & Henry 2006). Further, "there is even a danger that all new developments in a particular tradition that draw on aspects of the earlier tradition are now labeled as 'integrated'" (Lanier & Henry 2004, p. 344). While combining theoretical frameworks provides a comprehensive all-inclusive integrated criminology, it can be very confusing and lacks the kind of precision at the various conceptual, operational, causal, and analytical levels discussed earlier.

In addition, "none of the integrated theories have attracted wide support, partly because the integrations have been selective and partial, reflecting the division and politics of the discipline" (Agnew 2011, p. 191). In order to make a more reasoned assessment of whether integration is a valuable enterprise for criminology it is helpful to consider Robert Agnew's "unifying criminology," which is one of the few systematic attempts at integration that transcends the limits discussed, though not without introducing some problems of its own.

28.4.1 Robert Agnew's Unifying Criminology

In *Toward a Unified Criminology*, Robert Agnew (2011) seeks to transcend the disciplinary divisions rooted in the discipline-based theories that constitute criminology. He argues that these theories are not so much competing as complementary, such that each explains different parts of the overall etiology of crime. Agnew suggests that "all theories of crime are relevant, including those that focus on the constraints to crime and on the motivations for crime [and] that criminologists need to pay much attention to bio-psychological factors, since the underlying traits that cause crime vary across individuals for reasons that are in part biologically based" (2011, p. 196). Because all theories have some relevance, the purpose of Agnew's integrative project is to lay the foundation for a unified theory of crime: "one that examines a broad range of crimes and incorporates the key arguments of all major theories and perspectives" (2011, p. 201).

Instead of trying to integrate already constituted theories, Agnew draws on core constitutive assumptions or fundamental premises about crime, people, law, and society found in each and every theory. On each dimension, Agnew assesses the contributions of different theories. He argues that recent developments in science and social-science knowledge make it easier for criminologists to assess the relative contribution of each theory's underlying assumptions to the overall etiology of crime, while acknowledging that each theory is only partial in its own explanatory power (2011, pp. 193–194). Agnew also acknowledges that many theories make contradictory assumptions, which need resolving.

First Agnew sequentially integrates definitions of crime, resulting in a definition with three elements. Crimes are actions that: (1) cause blameworthy harm as defined by local, national, or international law; (2) are condemned by the public, and (3) are sanctioned by the state. Second, Agnew explores the eternally debated issue of free will verses determinism to decide whether the behavior of crime is determined by forces beyond individual control or voluntarily chosen by active human agents, concluding that "behaviors fall along a continuum, ranging from fully determined to somewhat agentic," suggesting a limited or "bounded agency" which is enhanced by various factors and diminished by others (2011, p. 195). Agnew indicates that agency may result in a variety of outcomes, including crime, conventional behavior, and great achievement (2011, pp. 66–68).

Third, Agnew points out that research supports the view that humans express: (1) self-interest and rationality; (2) social concern for others, especially those members of an in-group, with whom they empathize, protect, cooperate, and engage in reciprocal activities for mutual support; and (3) capacity for social learning, which varies across individuals and social circumstances (2011, p. 196).

Fourth, Agnew says criminologists should pay attention to the ways social concern, social interest, and social circumstances are interrelated and coproduce the very human agents whose behavior is manifest as "individuals," identities, and human subjects, as part of the total social matrix. Integrative criminologists want to know the reciprocal interactive effects at different levels of the structure and culture over the life course and over time.

This leads Agnew to a fifth core statement, in which he posits that "Group conflict generally increases crime among oppressors and oppressed, although certain types of conflict might reduce crime among the oppressed" (2011, p. 197).

Sixth, Agnew integrates theories of causation, recognizing that it is important to examine not only a range of macro- and microcauses, but also "the relationship between these causes, thereby providing a better sense of why they vary and how they work together to cause crime" (2011, p. 162). He states that conflict theory focuses on the larger macrolevel causes, but often neglects individual or micro-level mechanisms, whereas mainstream theories focus on individual-level causes, neglecting the ways these are impacted by the wider social-environmental context. Thus, unified criminology "draws on both conflict and consensus perspectives" and therefore "provides a good vehicle for cross-level integration" (2011, p. 162). Importantly, Agnew also recognizes that causes do not necessarily apply to all people and all types of crime, but that causes differ across groups, shaped by power, position, social context, and they vary depending on the type of crime, which varies across different societies.

Interestingly, while observers may see Agnew's project as the most developed approach to integrative approaches to law, justice, and criminology, Agnew (2013) points out that he *does not* develop an integrated theory of crime: "I integrate the underlying assumptions that criminologists make . . . For example, I integrate the assumptions that criminologists make about human nature, developing a more complete description of human nature . . . [but] it is not appropriate to evaluate this description using criteria developed for integrated theories" (2013, pp. 81–82).

Agnew uses the core assumptions or presuppositions as a vehicle for theoretical integration, which represents a major innovation in criminological thinking about crime. However, Agnew does not tell us precisely what concepts and propositions should be integrated, in what ways, and at what level, or how much contribution each theoretical explanation makes to the overall causal explanation.

In the later stages of his project Agnew glimpses a problem that perhaps threatens to undermine the whole interdisciplinary integration enterprise. In discussing the appropriate research necessary to better measure crime and its causes, he says that research on crime, human agents, and society is subject to ontological assumptions about whether social reality can be measured, which he claims raises the methodological problem of designing more effective measurement techniques to take account of both objective and subjective features of reality, since both affect the way crime is produced and the effectiveness of prevention and intervention.

Importantly, Agnew also recognizes the value of tapping multiple knowledge producers, seeing these not only as objective discipline-based knowledge production by criminologists in organized academia but also as spontaneous and less organized professional and subjective knowledge produced by practitioners and professionals in communities, in order to reduce the bias of existing measures. This raises the whole question of whether knowledge about law, justice, and criminology can be adequately integrated without a theory of knowledge production.

28.5 Beyond Integration of Disciplinary Knowledge: Toward a Transdisciplinary Theory of Knowledge Production

It is apparent from this brief review of integrative theory in law, criminal justice, and criminology that there are several parallels to the larger interdisciplinary project. Earlier I discussed what that meant for the wider literature, particularly the European literature, on the topic. Here, I explore the notion that knowledge is not the sole province of academics, academic disciplines, or departments of organized knowledge in universities. Rather, real-world problems are informed by a diversity of knowledge produced by multiple knowledge producers.

28.5.1 From Transdisciplinary Criminology and Criminal Justice to Integrative Pluralism

The interdisciplinary studies literature, especially in Europe, has moved from the concept of "interdisciplinary studies" to "transdisciplinarity," which has been defined in slightly different ways by different theorists. For example, in one definition transdisciplinarity means working across disciplines to develop an overarching synthesis. A second meaning of transdisciplinarity moves beyond the disciplines to other forms of knowledge production and explores how to begin to integrate these into the totality of explanation for behavior (see Klein, this volume). Since mega and complex problems such as crime require comprehensive policy and practice solutions involving collaboration among a hybrid mix of actors from different disciplines, professions, and sectors of society, this version of transdisciplinarity involves multiple knowledge producers. Thus transdisciplinarity, "unlike interdisciplinarity, crosses both disciplinary boundaries and sectors of society by including stakeholders in the public and private domains" (Repko 2008, p. 15).

28.5.2 The Contribution of Richard Carp's "Knowledge Formations"

Richard Carp (2001) has pointed out that all "knowledge formations" (the term he prefers to "disciplines") are "partial and situated," rather than being "privileged site[s] of especially valid knowing" (2001, p. 71). Carp asks what forms of knowing should be included if those we currently include as "disciplines" are socially constructed, culturally and historically specific, and dynamically changing. He argues that we need to develop "integrative praxes that learn from multiple knowledge formations and fostering ongoing conversation among these praxes" (Carp 2001, p. 71).

To illustrate the point, Carp suggests that "we move away from thinking of the disciplines as unique sources or resources for knowledge and thought. We might instead imagine the disciplines as one sort of knowledge formation, of which there are several kinds. . . . Any of these and other knowledges may be useful or even necessary . . . for example, the varieties of local, vernacular, or cross-cultural knowledge that are sometimes critical for success" (Carp 2001, pp. 74–75).

Thus in reconceiving interdisciplinary studies, Carp prefers the notion of "learning from multiple knowledge formations" rather than restricting analysis/policy to those contained among disciplines in the academy (Carp 2001, p. 75). Indeed, the limits of the academic organization and hegemonic control of such knowledge by disciplines, and the marginalization of competing knowledge formations, including interdisciplinary formations, have been well documented.

Carp's suggestion, then, is that we begin a dialogue about the kind of schema for knowledge integration that would allow us to be explicit about what kinds of knowledge we are integrating from multiple knowledge formations and whether, by selecting only some kinds of knowledge, we might be excluding other kinds. In short, we need a framework for interdisciplinary integrative pluralism (Augsburg & Henry 2016).

28.6 Conclusion

In an attempt to explore integrative interdisciplinary thinking in law, criminal justice, and criminology, I have pointed to new thinking in the field of interdisciplinary studies that holds the promise of moving criminology, law and society, and criminal justice from the limited version focused on the integration of organized academic knowledge, to a broader transdisciplinary approach that recognizes a plurality of forms and levels of knowledge production. The future of effective policy formation for social intervention to prevent and/or reduce harm-producing behavior is one that builds policy on a comprehensive knowledge about multiple contributing causes and ways to address them through a holistic approach to complex problems.

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CHAPTER 29

HEALTH RESEARCH, PRACTICE, AND EDUCATION

ANGUS MCMURTRY, KELLY N. KILGOUR, AND SHANTA ROHSE

Both interdisciplinary health science and interprofessional healthcare have grown rapidly in recent decades. Although there has only been limited cross-fertilization of ideas between the two areas, their emergence has been driven by a similar challenge: complex problems that are too broad or multifaceted to be solved through the logic of a single discipline. Several things distinguish these health-related fields from many other interdisciplinary areas. One is that the complex problems they deal with are literally matters of life and death, such as cancer, diabetes, substance abuse, and highly infectious diseases. Another is that their primary goal—whether in research or practice—is to improve the care and lives of people who suffer from these diseases. Finally, interdisciplinary and interprofessional health activities are generally carried out by teams of collaborating specialists. So issues of interpersonal dynamics, negotiation, and collaborative learning play an especially important role in the literature.

This chapter critically reviews the two fields of interdisciplinary health science research and the closely entwined areas of interprofessional healthcare practice and education. After briefly clarifying definitions, it describes the development of these two fields independently. Then it examines a number of major issues that have arisen within both these fields and compares the ways in which researchers and practitioners in those fields have dealt with them: Stakeholder engagement and transdisciplinarity, the complexity of human health, the development of more sophisticated theories of collaboration and teamwork, practical conditions that support collaboration and teamwork, and finally, issues of evaluation and measurement. The chapter concludes by noting the ways in which these fields might advance through a mutual exchange of ideas, as well as increased awareness of wider interdisciplinary literature.

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29.1 Definitions

Before exploring the above issues, however, we clarify several terms that are used frequently in this chapter.

- "Multidisciplinary" activities draw on two or more disciplinary perspectives in order to better understand or address a certain issue or problem.
- "Interdisciplinary" is used to describe activities that also attempt to integrate such disciplinary perspectives in a way that may lead to the development of new, overarching knowledge that transcends these perspectives (Repko 2008; see also Klein, this volume).

The term "interprofessional" parallels "interdisciplinary," in the sense that interprofessional activities seek to draw on and integrate diverse professional perspectives. However, the focus of interprofessionalism is more practical: better collaboration among professional practitioners with the goal of improved outcomes (e.g., in health and social care), rather than the development of new domains of knowledge (D'Amour & Onadasan 2005).

"Transdisciplinary" appears at several points in this chapter too. There is less consensus surrounding use of this term. In this chapter, we focus on two common meanings articulated by Klein (2010). One is employed by team science researchers based primarily in the United States. They define transdisciplinary research as the development of "shared conceptual and methodological frameworks that not only integrate but transcend their respective disciplinary perspectives" (Klein 2010, p. 79). This definition is compatible with the definition of interdisciplinarity above.

Another definition of "transdisciplinary" is problem-driven research that involves collaboration among not only academic researchers but also nonacademic stakeholders (Klein 2010). These stakeholders could be a private sector company interested in technical product development, members of a local community pursuing sustainable development, or—more relevant to this chapter—patients, family members, or health lobby groups seeking input into the health research, policy, or practice that affects them or those whom they represent.

29.2 Interdisciplinary Health Sciences

With advances in health sciences, many historic causes of death and illness, such as polio and smallpox, have been largely eradicated. The challenges we now face, such as type II diabetes, cancer, dementia, mental illness, and substance abuse, are unlikely to be cured by a single medication or vaccine. They are complex phenomena that involve interacting processes at multiple levels, "from the cellular to the socio-political level" (Terpstra et al. 2010, p. 508). At the same time, health scientists and their fields of expertise have become increasingly specialized. As a result, there is a growing trend towards research

> in which team members with training and expertise in different fields work together to combine or integrate their perspectives in a single research endeavor . . . as a means to engage in expansive studies that address a broad array of complex and interacting variables. (National Cancer Institute n.d.)

Not surprisingly, governmental organizations like Health Canada and the US National Institutes of Health (NIH), have dedicated significant resources to such collaborative, interdisciplinary science initiatives. The Canadian Institutes of Health Research (CIHR) program, for instance, was founded in 2000 to replace several more fragmented programs. From the beginning, it was organized around four pillars ("biomedical, clinical, health system and services, and population and public health") and had the goal of fostering linkages and breaking down barriers among different health research fields (Hall et al. 2006, p. 765). While CIHR has been critiqued for not living up to its interdisciplinary goals in practice, its orientation has nonetheless been perceived as progressive (Hall et al. 2006).

In the United States, the practice and study of "team science" have been more fully developed through the NIH and constituent institutes and centers such as the National Cancer Institute (NCI). The term "team science" refers to large (50–200 person), multiyear, collaborative science initiatives that in most cases are geographically and institutionally dispersed (Stokols et al. 2008a, p. 78). A new field of inquiry, the "science of team science" (SciTS) emerged in the 2000s, as a response to funding agencies' desire to better understand the outcomes of team science initiatives and to determine the best ways to support collaborative efficiency and productivity.

A cornerstone publication was an issue of the *American Journal of Preventive Medicine* titled "The Science of Team Science: Assessing the Value of Transdisciplinary Research" (Stokols et al. 2008b). Its goal was to define the boundaries of the field, what theoretical frameworks to use, how best to support interdisciplinary collaboration, and how to measure success (both in research terms and in practical policy outcomes). More generally, the authors wished to provide the field with "the conceptual coherence of a more established and widely recognized scientific paradigm" (Stokols et al. 2008a, p. 80).

Since then, publications and resources related to team science have grown rapidly. Among the significant contributions are the "Team Science Toolkit," an interactive website designed to help those who wish to support, conduct, and study team-based research (National Cancer Institute n.d.); a special issue of the *Journal of Translational Medicine and Epidemiology* focused on collaboration science (Lotrecchiano 2014); and a report from the US National Research Council on improving team science effectiveness (Cooke & Hilton 2015). In the SciTS field, the term "interdisciplinary" is used to describe activities that merely integrate disciplinary perspectives, while "transdisciplinary" is reserved for activities that not only integrate but also develop transcendent, overarching perspectives. More recently, the term "transdisciplinary" has been expanded to encompass nonacademic stakeholder involvement and the translation of research findings into new healthcare protocols and treatments (Lotrecchiano 2014).

29.3 Interprofessional Practice and Education

It is difficult to determine the origin of interprofessional health practice (IPP), as scattered references to it go back at least 100 years. What is undeniable is that in the past two decades, there has been "increasing worldwide interest in how better teamwork and collaboration among health, social care and other professionals, working in partnership with clients and their families, may more effectively address challenges in health promotion and health care delivery" (Barr et al. 2005, p. xi).

Collaborative practice has become the standard of care in many healthcare settings. A number of recent national reports across the developed world have described IPP as a key factor in health system renewal, through promoting greater patient quality of care, shorter hospitalization stays, and improved cost efficiencies. Although still inconclusive and debated, there is evidence that collaborative delivery models can be more effective and efficient than traditional ones (Centre for the Advancement of Interprofessional Education [CAIPE] n.d.).

Interprofessional practice is defined as "active and ongoing partnership, between two or more professions, who work together to solve problems or provide services" (Reeves 2009, p. 143). Collaborating professionals may include physicians, nurses, pharmacists, social workers, nutritionists, physiotherapists, occupational therapists, counselors, educators, and many others. The exact configuration of professionals, and the form their collaboration takes, may vary widely depending on the context: hospitals, community health clinics, long-term care facilities, and doctors' offices, as well as specialized practices such as mental health, child protection, palliative care, infection prevention and control, and so forth.

IPP does not usually occur spontaneously or smoothly. Many barriers stand in the way, including uniprofessional education and socialization, work and administrative structures premised on specialization, legal and compensation rules founded on individual practice, and the often contrasting paradigms employed and applied by differing health and social care professionals and their respective professional associations (Gilbert & Bainbridge 2005). Simply working together may not lead to collaboration and respect; indeed, it may simply reinforce negative stereotypes, professional tensions, and conventional hierarchies (Baker et al. 2011).

Explicit interprofessional education (IPE) in both prelicensure schooling and on-the-job continuing education settings has therefore expanded dramatically in the past two decades. A widely used and inclusive definition of IPE suggests, "Interprofessional Education occurs when two or more professions learn with, from and about each other to improve collaboration and the quality of care" (Centre for the Advancement of Interprofessional Education [CAIPE] n.d.).

The World Health Organization now recognizes IPE as a necessary component of every health professional's education. University-based academic health centers in the United States have offered interprofessional health team education for several decades. The Centre for the Advancement of Interprofessional Education (CAIPE) has played central role in the UK since 1987. The Canadian Interprofessional Health Collaborative (CIHC) was founded in 2005, and Health Canada began funding IPE initiatives in the 1990s (Barr et al. 2005). Professional accreditation bodies in many other countries now include learning outcomes or objectives that emphasize teamwork and professional interactions.

Several journals have been established on the topic of interprofessional research, practice, and education, including the *Journal of Interprofessional Care* (JIC) and the *Journal of Research in Interprofessional Practice and Education* (JRIPE). There are also national and international conferences focusing on interprofessional care, such as "Collaborating across Borders: An American-Canadian Dialogue on Interprofessional Health Education (CAB)" and the "All Together Better Health (ATBH) Conference."

While some practitioners and researchers rooted in the empirical sciences have been reluctant to apply theoretical lenses to IPE, others have drawn on an eclectic range of perspectives, from traditional psychological viewpoints like behaviorism and information processing, to constructivism, sociology, systems theory, and poststructuralism. Unfortunately, few IPE researchers have drawn on wider literature on interdisciplinarity or transdisciplinarity and the conceptual guidance they provide for integrating differing perspectives and interests. (The lack of cross-fertilization among these fields is discussed in the second half of this chapter.)

This eclectic range of theoretical perspectives has provided many valuable insights for researchers and educators. But it also means that IPE literature lacks theoretical consensus. Indeed, there have been such a variety of IPE initiatives in so many different countries and contexts—with each introducing its own distinctive terminology—that many have observed that the field continues to be a "semantic quagmire" (Freeth et al. 2005, p. 45).

Interprofessional education may take many forms, from uniprofessional education that prepares individuals for team-based practice, to collaborative problem solving in multiprofessional student groups, to reflective practice within existing clinical settings (Barr et al. 2005). There is debate regarding the best time to introduce professional students to IPP and IPE. Some authors support early initiatives in the first year of professional training. Others argue that students need to solidify their own professional identity, roles, and responsibilities *before* engaging in collaborative activities and the complexity of interprofessional (IP) teamwork (Reeves et al. 2012).

29.4 Issues in Interdisciplinary Health Research and Interprofessional Practice and Education

The first half of this chapter briefly described the independent development of interdisciplinary health sciences, on the one hand, and IPP and IPE, on the other. The second half examines major issues that have arisen in these parallel fields and examines how they have been articulated and addressed. Because there has been surprisingly little interaction between these fields—not to mention the wider literature on interdisciplinarity—thinkers in each field have often generated similar ideas in isolation. The specific issues we examine are stakeholder engagement and transdisciplinarity, the complexity of human health, the development of more sophisticated theories of collaboration and teamwork, the practical conditions that support collaboration and teamwork, and finally, evaluation and measurement.

29.4.1 Stakeholder Engagement and Transdisciplinarity

One recent trend in team health science is the inclusion of nonacademic and nonclinical stakeholders (Bammer 2005). The aim of such research is to engage stakeholders—such as companies, communities, families, and patients—not only in identifying problems to be solved, but also in co-constructing the knowledge produced. The reason for such participation is twofold: first, it is believed to improve the context-sensitivity and outcomes of the research; second, stakeholders are more likely to integrate and implement knowledge that they themselves had a role in creating (Terpstra et al. 2010).

As in the field of interdisciplinary team science, a growing trend in IPP is the engagement of stakeholders. In this case, though, the focus is on healthcare practice rather than knowledge-generation and the stakeholders are typically patients and their families. The terms "patient engagement" or "patient involvement" are generally used in this context rather than "transdisciplinarity." The goal of this movement is to empower patients and to take advantage of their unique insights as recipients of care, as well as to involve them, their families, and their communities in healthcare teamwork, decision-making, and partnerships (Canadian Foundation for Healthcare Improvement n.d.; Moreau & Cousins 2011). One new and promising elaboration of patient engagement thinking is relationship-centered care; it emphasizes the centrality of reciprocity, affect, and ethics within the relationships among patients, clinicians, and other stakeholders, and also draws on insights from complexity theory and organizational learning (Gaboury et al. 2011).

In both fields there have been challenges related to stakeholder engagement. These include difficulty in recruiting people and organizations, miscommunication among academic and nonacademic (or clinical and nonclinical) participants, issues related to ethics and group dynamics, and the fact that engagement of a wider range of stakeholders may significantly increase the time and resources necessary to achieve consensus and implement changes (Bammer 2005; Moreau & Cousins 2011).

29.4.2 The Complexity of Human Health

In both health science research and interprofessional healthcare practice and education, there is a growing realization that most pressing human health problems are multifaceted and multilevel. For example, type II diabetes involves not only bodily systems and subsystems but also diet, exercise, lifestyle, economics, city planning, and cultural norms. Health issues should thus be understood more systematically or holistically, and better interventions or solutions may be developed by drawing on a variety of disciplinary or professional perspectives. As Terpstra et al. (2010) write, "the lesson learned from the HIV/AIDS epidemic, as well as other health challenges such as diabetes, cancer, and asthma, is that health is a complex phenomenon, and solving health problems will require an integration of diverse knowledge" (p. 509).

The complexity of health has been acknowledged and articulated by many progressive health science researchers for the past 15 years. Researchers associated with the Plexus Institute (http://www.plexusinstitute.org), for instance, have produced a wealth of research oriented by a multifaceted, complexity science–based understanding of human health and healthcare organizations. A similar sensibility is shown by researchers associated with the University of Arizona's Program in Integrative Medicine: "Much of conventional medical research focuses on subsystems of the body. Integrative medical research is interested in whole systems and uses complexity science and whole systems approaches to study complex packages of care" (Arizona Centre for Integrative Medicine n.d.).

This perspective on human health has perhaps been studied most extensively by thinkers associated with SciTS initiatives. In "The Social Determinants of Cancer," for instance, Hiatt and Breen (2008) highlight the need for a transdisciplinary, multilevel approach to cancer research and care—one that addresses not only the biological nature of cancer and clinical interventions, but also crucial behavioral, social, and environmental factors. This "socioecologic" or "cells-to-society" approach is shared by Mabry et al. (2008, p. 141); their fascinating illustrations include graphical models of the causes, diagnoses, and treatments of diabetes and the manner in which social and psychological stresses influence the microenvironment of tumors. More explicitly oriented by complexity science, Leischow et al. (2008) depict both diseases and healthcare systems' responses to them (including team science initiatives) as complex, dynamic, multifactoral, nonlinear systems. Traditional scientific disciplines' knowledge "silos" are useful, they write; but to truly address these complex issues, one must take a transdisciplinary approach that sees the silos as part of a larger system (p. 197).

Unfortunately, these SciTS authors have made only limited use of existing literature linking interdisciplinarity with systems thinking and complexity science. Such links have been articulated for many years by thinkers associated with the Association for Interdisciplinary Studies (AIS) (Newell 2001) as well as the Plexus Institute and the University of Arizona's Program in Integrative Medicine (see above). As a result of this omission, SciTS authors have largely "reinvented the wheel," theoretically speaking. While their thinking in the areas of systems and complexity is tremendously sophisticated in some respects—such as biomedicine, epidemiology, and quantitative analyses—they are not as advanced in other areas—such as social science, epistemology, and complexity thinking—as they might otherwise have been.

Explicit acknowledgment and theorization of the complexity of human health has been more limited in the fields of IPP and IPE. Authors have used complexity science to understand healthcare policy and organization (Kernick 2004), healthcare education (Mennin 2010), and IPE (Cooper et al. 2004). But few have yet used complexity science's multifactorial, ecological perspective on human health as a framework for understanding IP collaboration (McMurtry 2010).

29.4.3 Developing More Sophisticated Theories of Collaboration and Teamwork

Within the broader fields of professionalism and interdisciplinarity, authors have long offered sophisticated theoretical accounts to explain the dynamic relationships among the disciplinary or professional knowers and their knowledge(s). Issues such as class, gender, history, law, economics, and professional socialization typically play a central role in these accounts. The literature on IPP and IPE has gradually incorporated such sociocultural theoretical analyses, moving from relatively naïve, practical approaches to more critical perspectives.

Many early IP authors attributed problems and tensions within teams to practical factors like personality clashes, insufficient communication, and the need to articulate clear team goals. In the 2000s, this "practical" approach was critiqued by authors schooled in sociocultural theories for not acknowledging the deeper discrepancies of epistemology and power among differing professionals. Drinka and Clarke (2000) put it thus:

> In IHCT [interdisciplinary health care teams], the dimensions of communication most often discussed relate to issues involving personality clashes, role overlap and conflict, and the effective use of sharing of clinically important information. Absent is an examination of underlying problems with communication based on the professional differences among health care providers, including how they acquired particular values over the course of their education and subsequent clinical work experience. (p. 63)

An early example of this more socioculturally sophisticated approach is offered by the IP theorist Beattie (1995). He uses the anthropological metaphor of "tribes" to analyze health profession boundaries, arguing that each profession has its own explanatory framework or "cultural bias" (p. 20). Each of these professional frameworks finds its justification through differing sets of interests, roles, relationships, and social and institutional values.

Hall (2005) writes that, due to their silo-based, uniprofessional education and socialization, professions develop differing "cognitive maps"; as a result, they can look at the same thing and yet understand it very differently. Drawing on social theory, Hall argues that such professional differences arise through struggles for power and control. For instance, one profession may seek to heighten the contrast between itself and other rival professions in order to expand its authority. Given this focus on sociocultural factors, it is not surprising that Hall's (2005) suggestions for fostering effective interprofessional teamwork center on issues such as communication (team members making their cognitive maps and values clear to one another) and power (fostering equal status among team members).

This sociocultural understanding of interprofessional collaboration has been taken even further in recent years by theorists grounded in sociology, organizational learning, and other sociocultural perspectives (Lingard et al. 2012; Baker et al. 2011). As Barr et al. (2005) write, "Interprofessional education . . . needs to be broadened to embrace collaboration in its diverse dimensions, shedding naïve and idealized notions of teams, acknowledging intractable tensions resulting from rivalry and imbalances in power, and chronic instability in many working relations" (p. 9).

This well-articulated critical, sociocultural theoretical perspective unquestionably adds many valuable insights. Not necessary. Readers already know the focus on this article and what the persepcti9ve is applied to. Unquestionably adds many valuable insights. This perspective can itself, however, be critiqued for having an insufficiently broad focus: Its persuasive explanation of interprofessional collaboration and education is offered strictly within the bounds of human knowing and culture. The complex material, biological and ecological objects, processes and systems with which professionals interact—the focus of the previous section—play little or no role in knowledge and practice and appear to be relegated to inert backdrops.

This exclusive focus on sociocultural dynamics has recently been critiqued by writers employing "sociomaterial" approaches—such as actor-network theory and complexity science—within the context of health professions education and interprofessional practice (Fenwick 2014; McMurtry et al. 2016). From a sociomaterial perspective, professional knowledge and practice are shaped by not only sociocultural dynamics but also interactions with and among bodies; other organisms, tools, spatial arrangements; and other such "material" forces. Learning and knowing are thus recast in terms of networks of effective relationships among both social and material actors, rather than as something "acquired" by individuals.

For example, an immunization campaign might be seen as a knowledge network that comes into being as people, policies, vaccines, needles, pathogens, buildings, and transportation routes are brought together to enact relatively stable and lasting practices. These latter material elements contribute to learning too; like people or social norms, they may enable or resist the establishment and maintenance of networks and thus what counts as knowledge or "facts." For instance, pathogens may evolve to resist vaccines, needles may become easier to use, transportation to clinics may get blocked, and user-friendly vaccination calendars may help ensure that appointments are kept.

The IPP and IPE writers' current emphasis on sociocultural examinations of collaboration also contrasts strongly with the team health science research described in the previous section. As we saw, to explain contrasts among disciplinarians' perspectives, SciTS thinkers focus on the differing factors, levels, or systems studied by health researchers: biomedical, personal/behavioral, social, environmental, and so on. Their differing insights or knowledge contributions are thus largely a function of the differing complex systems or phenomena with which they engage, rather than sociocultural power dynamics per se.

Indeed, the SciTS literature seems to have the opposite problem as the IPP and IPE literature. Its impressive scientific sophistication seems in many cases to be counterbalanced by a naivety with regard to sociocultural factors like power and politics. For instance, in their watershed 2008 issue of the *American Journal of Preventive Medicine*, SciTS authors identify the profound health consequences of socioeconomic influences like income disparities. But they fail to recognize that these findings are not politically innocuous or "neutral"—they lead toward discussions of wealth redistribution and other initiatives that would threaten entrenched economic interests. Similarly, in both (1) the 2014 special issue of the *Journal of Translational Medicine and Epidemiology* on collaborative and translational medicine and (2) the 2015 report for the National Research Council on effective team science (Cooke & Hilton 2015), authors recognize tensions among different disciplines and departments, as well as institutional obstacles to interdisciplinary research. They mostly fail, however, to link these factors to deeper political and economic power structures within research institutions and wider society.

Further theoretical development in the fields of interdisciplinary health research, on the one hand, and IPP and IPE, on the other, may therefore require different but complementary perspectival expansions. Those studying team science need to recognize the sociocultural implications of their research and perhaps involve more social scientists in their projects. And those studying IPP and IPE might benefit from broadening their frameworks for collaboration and teamwork beyond sociocultural factors to embrace the biological, material and ecological systems with which various professionals interact.

29.4.4 Practical Conditions That Support Collaboration and Teamwork

Within the fields of IPP and IPE, conditions to support effective collaboration and teamwork have been the focus of ongoing study, discussion, and policy for at least 20 years (Drinka & Clarke 2000; D'Amour & Onadasan 2005; San Martin-Rodriguez et al. 2005). Some commonly invoked factors include:

- professional competence
- communication skills (speaking and listening)
- flexibility
- respect for other professions' inputs
- trust
- shared responsibilities

- shared team goals and values
- rules for resolving conflict
- commitment and accountability
- institutional support and resources

The more comprehensive of these articles typically divide these factors into multiple levels—from smaller scale *personal* and *interactional* factors, to larger scale *organizational* and *conceptual* issues (e.g., San Martin-Rodriguez et al. 2005).

In the past decade, these practical conditions for teamwork and collaboration have been increasingly elaborated and critiqued through the lens of the sociocultural theories described above. Idealized notions of clear communication and shared responsibility, for instance, have been complicated through deeper consideration of paradigmatic differences and power imbalances among differing professionals (Barr et al. 2005; Drinka & Clark 2000).

Some SciTS researchers have begun to explore similar territory, specifically how to support inter- and transdisciplinary collaboration, as well as related questions such as the special challenges of leadership in these contexts. While this research is growing and offers valuable insights, SciTS thinkers have until recently made little use of extensive literature from the related field of interprofessional healthcare (see above) or wider literature on interdisciplinary integration (e.g., the Association for Interdisciplinary Studies [AIS]). They nonetheless arrive at much the same conclusions and multileveled frameworks, based on their own research and literature drawn from more distant fields like management and leadership.

Cooke and Hilton (2015), for instance, draw from research on corporations, the military, cognitive science, and several other areas to offer a multilevel framework for enhancing team science collaboration. As above, these factors are divided into multiple levels: individual, team, institutional/organizational, cyber infrastructures, and so forth. Two concrete examples of the conditions they deem important for effective teamwork are individual competencies (knowledge and skill) and strategies for managing conflict within teams.

In both team science and IP contexts, educational initiatives attempt to address these factors, for example, through readings and activities that support cognitive flexibility and interpersonal communication (Nash 2008; Freeth et al. 2005). Many of the conditions however, such as clinical practice culture as well as institutional commitment and support, lie beyond the control of students and educators. Awareness of the conditions that constrain or enable collaboration is nonetheless valuable for students when they enter practice, as it can help them to recognize where and how IP efforts may be successful or not, and what may need to change if those efforts fail.

29.4.5 Issues of Evaluation and Measurement

Many early thinkers in interdisciplinary health research and the closely linked fields of IPP and IPE believed that collaboration could be studied and engineered with the same sort of predictability, precision, and generalizability of other phenomena studied by health science and medicine (biochemical reactions, molecular structures, and so on). This orientation probably reflected both the disciplinary background of these early authors and pervasive institutional pressures to provide unambiguous evidence of interdisciplinary or interprofessional benefits—for instance, through quantitative measures of teamwork effectiveness, research publications, patient satisfaction surveys, or objective health indicators like infection control rates.

In the field of team science, for example, Hall et al. (2008) stress the importance of building "a strong science base that can be synthesized and generalized" (p. 249). Similarly, Mâsse et al. (2008) discuss their development of "psychometrically valid" quantitative evaluations for measuring integration and collaboration. A similar emphasis on objective, reproducible, and generalizable criteria is manifested in some IPP and IPE contexts. The influential *Journal of Research in Interprofessional Practice and Education*, for instance, articulates its scope using language such as "experimentation," "testable assertions," and "hypotheses" (Journal of Research in Interprofessional Practice and Education, n.d.).

Leading thinkers in both areas have argued that such positivist hopes are unlikely to be realized. In "Evaluation of Interdisciplinary and Transdisciplinary Research: A Literature Review," Klein (2008) uses inter- and transdisciplinary science researchers' own history and literature to complicate and challenge the idea of any sort of linear, simple, or settled evaluation procedure:

> Interdisciplinary and transdisciplinary research process and evaluation are grounded in the philosophy of constructivism. Appropriate evaluation is made, not given. It evolves through a dialogue of conventional and expanded indicators of quality . . . a single-best or universal method . . . would be antithetical to the multidimensionality and context-specific nature of interdisciplinary and transdisciplinary work. (pp. 122–123)

In lieu of such single-best or universal measures, Klein (2008) suggests seven more appropriate principles of evaluation for team science. These principles emphasize variability of goals, methodological pluralism; the negotiation of epistemic differences; the difficulty of separating cognitive, social, and contextual aspects of collaboration; and the need to adjust evaluative criteria as research evolves and unpredictable outcomes emerge.

In the context of IP healthcare, it is increasingly understood that effectiveness, whether in practice or education, is a complex and debated issue—albeit a very important one. For instance, effectiveness in IPP may take many forms: changed attitudes, improved collaborative behavior, transformation in the organization and delivery of care, improved health outcomes, and/or engagement of stakeholders like patients and members of the community. And positive outcomes in IPE for learners might include everything from more appropriate attitudes or perceptions, to new knowledge and skills, to demonstrated teamwork and/or contributions to care. A plethora of evaluation tools have been developed to measure these factors, yet many rely largely on self-reported changes in attitude and awareness rather than actual healthcare collaboration (Reeves et al. 2012).

Thus IPP and IPE effectiveness ought best to be measured in the messy, complex world of clinical practice and education, and evaluations are always rooted in "a particular paradigm or way of thinking about the world" (Freeth et al. 2005, p. 128). Evaluation measures that pretend to experimental objectivity and universal generalizability will therefore always be problematic. Those who seek to evaluate IPP or IPE, therefore, should carefully consider the specific needs and context of their program as well as the many possible ways in which success or effectiveness can be judged.

29.5 Conclusion

Both interdisciplinary health science research and IPP and IPE deal with complex and pressing issues like cancer, diabetes, substance abuse, and highly infectious diseases—quite literally, matters of life and death. Both fields are growing rapidly in size and sophistication. However, there is been surprisingly little interaction so far between these two fields—not to mention literature from other established interdisciplinary areas.

There are several opportunities for mutual learning and exchange of ideas that could benefit both fields. Interdisciplinary health researchers, for instance, are exploring in a very deep and detailed way the complexity of human health and how differing disciplinary perspectives are required to understand and interact successfully with the various systems involved. Those studying and designing IPP and IPE initiatives would benefit from incorporating these insights into models of collaboration. Similarly, IPP and IPE thinkers have developed sophisticated practical and sociocultural models for understanding and supporting teamwork and other forms of collaboration. Those who wish to research and support interdisciplinary team science would be wise to take advantage of these insights, rather than drawing exclusively on less directly relevant fields such as management.

There is reason to believe that increased collaboration between these interdisciplinary health-related fields will occur in the future. Publications like this volume and *Enhancing Communication and Collaboration in Interdisciplinary Research* (O'Rourke et al. 2013) are bridging diverse literatures in a philosophically grounded manner and making it easier for interdisciplinarians and interprofessionals to become aware of related realms of inquiry. Another forum for exchange between fields is events like *Association for Interdisciplinary Studies* annual conferences, which include a section on health, healthcare, and aging. These publications and events can themselves be seen as leading examples of large-scale interdisciplinary collaboration and knowledge translation.

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New Public Service through Coproduction

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New public service (NPS) is a proposal for public administration structured on a foundation of public interest, democratic ideals, citizenship, and community participation. It is a heuristic conceptualizing of public administration where ideals of the good society govern public services in general. New public service is an alternative approach to public administration from the perspective of normative principles, or premises, for the study and implementation of public service.

The normative principles or premises that structure NPS originate from central ideals: value people, not only productivity; serve citizens instead of controlling and running society; ensure accountability (despite the complexity of doing so); think strategically but act democratically; value citizenship more than entrepreneurship; view public interest as an asset shared by all; and serve citizens, not just consumers or users. Based on these premises, the production of public services for public good takes place through the effective participation of members of the community and their organizations.

The coproduction of public services is central to this process. This strategy allows for the participation of different organizations, including public bureaucratic organizations, private bureaucratic organizations, nongovernmental organizations, nonformal community organizations, and other community and citizenship groups. Their participation may take place through various forms: as volunteer work (for the good of society), as direct work (that aims to suppress public service expenditures through greater efficiencies), and as participation in production of public services (to promote societal control over the public apparatus of the State).

To summarize, NPS offers principles and premises to conceive of and to implement public services based on citizen and governmental coproduction. This goal requires citizen participation in elaboration, design, implementation, and evaluation of public policies, all based on common interest. From an academic perspective, NPS requires an interdisciplinary approach, combining knowledge from disciplines such as public administration, law, and political and social sciences. On one hand, NPS can benefit from these disciplines to analyze its practices, evolve its principles, and increase its scientific background. For instance, a common definition of coproduction is still lacking, requiring collaboration on a conceptual and methodological framework (Brandsen & Honingh, 2015). On the other hand, once included as a multidisciplinary topic, NPS can foster current disciplines to include profession-based curricula and new programs dedicated to public administration.

Additionally, citizen coproduction posits the possibility of NPS as transdisciplinary knowledge, requiring integration of knowledge and actions by representatives of academic disciplines and fields as well as sectors of society "beyond university walls" (Frodeman 2014). This prospect is foreshadowed by the variety of fields that are already considering NPS principles to advance knowledge and problem solving, including e-government (Rose et al. 2015), smart cities (Bolivar 2016), government e-participation and crowdsourcing (O'Brien 2015), and social procurement (Barraket et al. 2016). All these fields share the principle of inclusion of a broad range of actors, both academic and social. Inclusion and, particularly, knowledge integration grounded on a systemic interaction between different actors are central concepts to transdisciplinarity (Hirsch Hadorn et al. 2011; see also Pohl et al., this volume).

Both interdisciplinary and transdisciplinary NPS can offer new educational approaches to colleges of business, public administration, and social work. The NPS principles have already been

(*cont.*)

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New Public Service through Coproduction (cont.)

pointed out as relevant additions to public administration curricula (Hewins-Maroney & Williams 2007). Another prominent scenario is the introduction of NPS principles in professional educational programs, either in practical courses such as nonprofit organization management (Denhardt et al. 2015) or integrated curricula, based on the three pillars of public administration—the legal, the managerial, and the political (Zalmanovitch 2014).

In short, coproduction and NPS have a multidimensional relationship: first, they can work as mutual constructs (i.e., coproduction is a NPS principle and NPS is a mandatory reference to coproduction studies); second, NPS can be fostered as an interdisciplinary field based on coproduction among several disciplines; and third, social and scientific coproduction studied as a transdisciplinary subject can also help NPS to evolve as a practical paradigm to public services.

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CHAPTER 30

INFORMATION RESEARCH ON INTERDISCIPLINARITY

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For decades, interdisciplinarity has been a priority in research and education. Universities and funding agencies have invested in initiatives to break down disciplinary silos of research and education and engineer platforms for cross-disciplinary collaboration. As we hear more about the promise of interdisciplinary approaches a new emphasis has emerged on data-intensive discovery. In response to advances in information technology and the growth of digital information, this "fourth paradigm" of research is not only distinct from traditional empirical and theoretical paradigms in science but also from the more recent computational paradigm of simulation (Hey et al. 2009). This paradigm focuses on harnessing large volumes of digital data for informatics and "big data" approaches to inquiry. Once associated primarily with sciences such as bioinformatics, data-intensive research is now pervasive across disciplines. The implications for interdisciplinarity may well be profound. New modes of publishing coupled with expectations for open access to publications, data, computer code, and other digital research products are becoming the norm in scholarly communication.

In some ways we are already at a pinnacle of access and use of information for interdisciplinary scholarly work. Information across disciplines has never been more abundant and accessible; communication and exchange of information across distributed research communities have never been more rapid. From the perspective of the information professions, however, we are far from realizing the potential of information systems and services for fueling interdisciplinary research. Moreover, the emphasis on volume and velocity in data-intensive research has underplayed "the diversity of interdisciplinary data and the need to interrelate these data" to understand complex problems (Parsons et al. 2011). We are in an era of transition, moving from homogeneous, centrally controlled, local information systems to heterogeneous, widely distributed, coordinated networks (Edwards et al. 2007).

Information research on interdisciplinarity is concerned with this complexity and how it impacts the production and use of information by research communities. Ultimately, information research is about optimizing information resources, systems, and services for researchers working across disciplinary boundaries, including the many scholars and scientists turning to data-intensive modes of research. As aspiring hubs of interdisciplinarity in academia (Mack 2012), research libraries are a primary place of application for

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information research on interdisciplinarity. While acknowledging that many kinds of organizations across sectors are invested in marshaling information and data across disciplines for research, problem-solving, decision-making, and innovation, in this chapter we provide an overview of research on interdisciplinarity from the perspective of the field of library and information science (LIS).

Our aim is to illustrate the scope of interests and issues in the field and to highlight significant areas of scholarship and practice. We begin by providing background on the intellectual perspectives and professional demands that inform how the field addresses interdisciplinary information problems. The next section covers two primary approaches to LIS research on interdisciplinarity: *bibliometric* research, which produces statistical analyses of patterns and flows of information among disciplines, and *information practices* research on the activities and materials involved in the conduct of interdisciplinary work. We then examine the applied dimension in research libraries—how they are responding to the rapid rise in the conduct of interdisciplinary scholarship and concurrent advances in digital content and information technologies. In conclusion, we identify important paths for information research in advancing interdisciplinary knowledge production in the digital age.

30.1 Interdisciplinarity and Library and Information Science

Library and information science is concerned with access to information—how to collect, organize, manage, preserve, search, retrieve, and disseminate information in alignment with the needs of people and communities. This broad purview has required LIS to evolve as an interdisciplinary field in its own right. The roots of the field reach into communication, cognitive science, computer science, linguistics, and philosophy of science. Current cognate disciplines include information systems, information management, human-computer interaction (HCI), computer-supported cooperative work (CSCW), and science and technology studies. In information science, the basic research arm of the field, information is the object of study, as are all human and machine-based processes by which people become informed. With this scope, information science provides the intellectual foundation for the work of librarians and information professionals in all kinds of organizations.

As noted by the economist Kenneth E. Boulding (1968), without professions of scholarly exchange like librarianship, the body of knowledge would be a "mere pile of intellectual accumulations instead of an organic and operating whole" (p. 147). Early leaders in LIS education referred to the theoretical foundation of librarianship as "social epistemology" (Shera 1972) to reflect the field's basic interest in how knowledge is coordinated, integrated, and used by people. This conceptualization emerged prior to, and remains somewhat distinct from, contemporary academic discourse on social epistemology in philosophy (Goldman 1987; Fuller 1988). It was a direct response to the profession's need to guide development of collections and services for library users with a deep understanding of the production, distribution, and utilization of the intellectual materials collected by libraries. From this foundational perspective, it is evident why the information problems associated with interdisciplinarity became a strong research focus in LIS and a point of synergy between LIS and other social sciences with intellectual interests in knowledge production (Klein 1996b; Palmer 1996).

While few institutions are immune to the impacts of interdisciplinarity, in academia research libraries are particularly vulnerable, and vital, to the forces at play. They have responsibility for information systems and services across all academic fields, a function of their unique and complex missions to support research, scholarship, and teaching; advance the development and transmission of knowledge; preserve intellectual heritage; and contribute to the common good. Libraries have always been part of the fabric of disciplinary change and the mechanisms for interaction among disciplines. The scholars and scientists that libraries serve are continually influenced by "the push of prolific fields and the pull of strong new concepts and paradigms" (Klein 1996a, p. 56). As disciplines grow, split, and merge, research libraries need to adapt to the escalation in interdisciplinary research and the concurrent changes in how researchers work with, produce, and disseminate information.

In the professional discourse of research librarianship, interdisciplinary themes were evident as early as the 1950s, as leaders drew attention to significant challenges for information systems and services resulting from the complex interrelations among disciplines and tensions between specialization and synthesis in knowledge production (Clapp 1954; Berthel 1968). When user-centered approaches to information research emerged in the 1960s (Menzel 1966), studies began to address the need for cross-disciplinary information access in contemporary scholarship and the information problems experienced by researchers crossing disciplinary boundaries. Decades later, these problems are more pronounced and disruptive than ever. Inherently interdisciplinary fields, such as digital humanities and the informatics branches emerging in many disciplines, are now commonplace on campuses across the country. The information systems they depend on consist of an array of formal and informal, commercial and open access digital libraries, data repositories, information services, and other various venues of scholarly communication distributed across sectors and organizations across the globe.

The phenomenon of information scatter is at the heart of practical and intellectual information problems faced by interdisciplinary scholars (Bates 1996). Scatter has been a unifying concept for much research on interdisciplinary information, fundamental to operationalizing human and technological aspects of how interdisciplinary information is searched for, identified, evaluated, and applied. For example, comparative analyses of topic scatter across databases have been central to progress in interdisciplinary information retrieval, and cross-disciplinary search exploits concepts and terms that connect variant and dispersed disciplinary vocabularies (Smith 1974; Weisgerber 1993; White 1996). Groundbreaking information science advances in literature-based discovery (LBD), pioneered by Don Swanson, were predicated on finding intellectual links in scattered literature. Swanson produced a series of valid biomedical discoveries with his technique for identifying scattered but complementary results in disconnected published papers, and his conceptualization of "undiscovered public knowledge" spawned a generation of further innovation in literature mining (Swanson 1986).

In essence the "bibliometric" and "information practices" approaches in research on interdisciplinarity, covered below, are aimed at understanding and managing scattered information. Bibliometric studies are particularly effective for illustrating the influence of scatter on growth and change in knowledge structures. Studies of information practices explain the actual work performed and problems encountered by scholars trying to find and use scattered information. Both approaches have practical applications for the development of libraries and information systems, and they also contribute to our basic understanding of how disciplines interact and the conditions that promote and deter the conduct of interdisciplinary research.

30.2 Bibliometric Research

Bibliographic sources provide a rich body of evidence for studying relationships among disciplines and by extension the connections and patterns that represent and produce interdisciplinarity. Statistical studies of disciplines, as represented in catalogs of literature and other bibliographic sources, date back at least to the statistical bibliography work of E. Wyndham Hulme (1923), a librarian at the British Patent Office. But the renaissance in bibliometrics was led by Eugene Garfield, founder of the Institute for Scientific Information (ISI) and their citation indexing services that began in 1961 with the *Science Citation Index*. A monumental innovation for bibliographic access, citation indexes also provided systematic data that could be leveraged to examine disciplinary relationships through a range of indicators, such as disciplines referenced or cited by authors, disciplinary affiliations of coauthors, structures of co-citation clusters, and co-word associations among journal titles. Citations function as symbols that represent the ideas of authors and markers of intellectual attribution and influence (Small 1978). They can be analyzed at various levels, including the organization, research specialization, discipline or subdiscipline, or across a broad range of fields to track and measure intellectual lending and borrowing across disciplinary boundaries (Pierce 1999). Today structured bibliographic data are widely available online from multiple sources, and bibliometric and webometric methods have become tools for researchers working in a range of fields beyond LIS (Thelwall et al. 2005).

In LIS, localized bibliometric studies and analyses of broader citation trends have been used to inform research library functions, especially collection development and administration of information resources and services. In one prototypical application, a study showing a high level of biology and physics citations among chemistry faculty informed reorganization of disciplinary service departments into a general, multiscience unit (Hurd 1992). Local assessments of citation patterns are also used to guide resource allocation and for the compilation of core journal lists for academic departments, programs, or research centers (Kushkowski et al. 1998; Kushkowski & Shrader 2013). Behind these local citation patterns lie the broader cross-disciplinary trends evident in national and international bodies of bibliographic data that are of great value for higher level strategic planning for research libraries in the broader context of academia and scholarly communication.

Bibliometric analyses have made important contributions to our understanding of how journals function as information intersections for interdisciplinary scholarship. For example, Rinia et al. (2002) applied three measures to 643,000 articles from the *Science Citation Index* to assess the "relative openness" of journals to articles from outside disciplines. Basic life sciences ranked highest on impact on other disciplines and computer science was among the lowest. This openness dimension holds promise for further assessment of characteristics of high-impact information sources for advancing interdisciplinary integration. In a complementary study by Morillo et al. (2003), measures of external links, diversity, and strength of relationships among nine research areas determined that biomedicine and engineering were highest in disciplinary relationships and humanities the lowest. Through multiassignation of journals to disciplinary categories in ISI's science, social science, and humanities citation indexes, the approach detects general increases in specialized journals in interdisciplinary categories and a higher level of interdisciplinarity in new categories of scholarship.

These structural bibliometric studies are distinct from spatial analyses that aim to represent the "landscape or space within which science operates" (Wagner et al. 2011). An expansive analysis by Boyack et al. (2005) mapped the "global structure of all of science," applying five intercitation and three co-citation frequency measures to 16.24 million references representing 7,121 science and social science journals. The hubs and links that emerged highlighted strong interdisciplinarity in biochemistry, with weaker multidisciplinary networks in medicine, ecology/zoology, social psychology, clinical psychology, and organic chemistry. Leydesdorff's (2007) network measures of closeness and betweenness, applied to 7,379 journals, captured the influence of engineering on interdisciplinary progress in biotechnology and demonstrated the strength of betweenness centrality as an indicator of interdisciplinarity. As seen with the structural techniques discussed above, spatial analyses can also provide important insights at the journal level, for example, by locating titles that function as the central nodes in emerging interdisciplinary networks. Bibliometric alternatives to traditional journal rankings are a welcome advancement, since current measures used in many research evaluations have been shown to introduce bias against interdisciplinary fields (Rafols et al. 2012).

30.3 Information Practices Research

Studies of interdisciplinary information practices are an important complement to bibliometric research and its dependence on citations, which are abstractions far removed from the actual day-to-day work and intentions of scholars. The "information practices approach" emphasizes the sociocultural dimensions of disciplines as a primary influence on the information activities of scholars and scientists (Palmer & Cragin 2008). Studies of information practices draw on a range of social science methods, particularly surveys, interviews, and ethnographic case studies. Multimethod techniques are commonly employed to increase the validity of results from smaller qualitative studies or to add context to patterns identified through more general survey techniques. While bibliometric studies have concentrated primarily on the sciences, information practices research has branched out into the humanities and the social sciences, as well as the sciences, investigating information work in domains such as environmental science, women's studies, and ethnic studies. Many studies are "domain analytic" in nature, taking a targeted approach to a subdiscipline or some other formalized research community. As units of analysis, domains are cultural entities that provide a more accurate representation of the process of research than broader, conventional disciplines. They are especially effective for comparative analyses that draw out differences in norms and practices in the adoption of information technologies and changes in the types of research products used and valued by a domain (Fry 2006; Weber et al. 2012).

The growing research community in the science of team science (Börner et al. 2010; Stokols et al. 2008) examines multidisciplinary collaborative teams as particularly rich microcosms of information transfer and other processes important to the management and evaluation of interdisciplinary research. Studies of collaborative practice have shown, for instance, that much of the information exchanged in science and social science teams is fact-based, but "know-how" related to research processes and methods is critical to supporting interdisciplinary projects (Haythornthwaite 2006). Recent work has also shown that affiliation with an interdisciplinary center appears to increase the practice of collaboration as well as dissemination into new fields (Bishop et al. 2014). Of the various objects that play an essential role in cross-disciplinary collaboration (Nicolini et al. 2012), information artifacts and technologies are arguably among the most significant for advancing learning and integration across disciplines. While integral to collaboration at a distance, digital information and information technologies are difficult to study and there are many challenges in interpreting their ultimate impacts on knowledge creation.

Since interdisciplinary researchers are considered a "significant and distinctive class of scholars" in their own right (Bates 1996, p. 163), numerous studies have examined interdisciplinary information practices within large multidisciplinary populations of scholars. For example, a survey of users of the national digital library in Finland corroborated earlier findings about scatter and interdisciplinarity, showing that scholars in high-scatter fields use more databases and have more difficulty keeping up with information across fields. The results also raised interesting questions about the role of browsing and the adequacy of cross-database keyword searching for interdisciplinary topics (Vakkari & Talja 2005). Patterns of scatter also emerged in a broad analysis of physics and astronomy, showing interdisciplinary subfields with scattered literature were more dependent on general search capabilities than strongly disciplinary subfields (Jamali & Nicholas 2010).

Information practices research has not yet produced a comprehensive account of the differences between disciplinary and interdisciplinary information seeking and use or the differences in practices among various interdisciplinary fields. It has, however, made substantive contributions to conceptual models of scholarly processes and requirements for information resources and tools to support interdisciplinary research. For example, a study of specialized interdisciplinary social scientists extended a widely accepted model of scholarly information seeking, adding three key stages—networking, verifying, and managing information—to the six established stages of starting, chaining, browsing, differentiating, monitoring, and extracting (Meho & Tibbo 2003). A model developed by Palmer (2001) identified the information needs and processes associated with three different modes of interdisciplinary inquiry: collaborators depend on strategies for obtaining specific information from outside fields; team leaders develop group routines for gathering information and also recruit partners to fill gaps in expertise; generalists invest in exploring and learning in new areas. Building on Palmer's framework, Foster's (2004) "nonlinear" model based on interdisciplinary scholars across a university emphasized the need for orientation and consolidation of information from key disciplines and the work of refining, sifting, and verifying to judge and integrate information during the research process. Foster's stages align with two distinct interdisciplinary scholarly practices associated with Palmer's model—*probing*, directed exploration of information in outside domains, and *translation*, the work of interpreting and applying terminology, concepts, and ideas from outside fields.

Probing and translation practices typify "weak information work," the very difficult and time-consuming information activities associated with research conditions common in interdisciplinarity—ill-structured problem space, lack of domain knowledge, and unsystematic research steps (Palmer et al. 2007). While on the surface interdisciplinary probing might seem to be associated with serendipity, a phenomenon of interest in information science especially in relation to browsing (Foster & Ellis 2014), probing is highly deliberate rather than ad hoc in nature. Translation comes into play as scholars encounter valuable theories, methods, and concepts through probing and then need to navigate and interpret disciplinary terminology and conventions for their valid application to a new body of discourse and practice. In the humanities, interdisciplinary scholars have a strong dependence on local or outside experts who serve as translators of concepts and ideas (Palmer & Neumann 2002). More generally, social networking is essential in making and maintaining the greater number of personal contacts needed to stimulate and validate ideas, open doors for sharing information, and for the exploration of interdisciplinary subject matter (Foster 2004).

Data management problems are acute in contemporary research, and there are many complications in the sharing and reuse of data for interdisciplinary research related to probing and especially for translation. For example, in automated data collection with sensors or other instruments, the contextual information on data acquisition previously documented in lab or field notebooks may no longer be systematically recorded and preserved. More generally, different fields may employ incompatible processes for data collection and analysis with variant terminologies for documenting these methods. Currently, the needs and expectations for managing and mobilizing data for interdisciplinary research purposes are not well understood or supported. Progress in data sharing and reuse across fields will depend on development of professional procedures and standards for cross-disciplinary data curation and integration. However, realizing the potential of open research data for interdisciplinary uses will ultimately hinge on transparency of the evidential cultures that dictate the meaning and valid application of data (Collins 1998).

30.4 Research Libraries and Interdisciplinarity

Research libraries are responsible for supporting scholarly work across all disciplines and are therefore uniquely positioned to encourage and facilitate interdisciplinarity through their information services and systems. In the current academic environment, it is not sufficient for libraries to react to trends in research activity and discourse after they are established. To be active agents in meeting the research mission of their universities, library operations must anticipate and foster new interdisciplinary areas as they emerge, especially in highly competitive research fronts and academic programs.

Historically, research libraries have been organized along departmental or disciplinary lines in their physical layout but also in the allocation of resources (Reynolds et al. 2012). More recently they have been adapting their services and experimenting with technologies to better support interdisciplinary research and teaching through a range of programmatic efforts (Mack & Gibson 2012): reorganization of internal departments to accommodate emergent fields; revised collection development policies; adoption of increasingly flexible knowledge classification structures for discovery systems; more creative staffing; and the extension of library services into external, collaborative research environments. In addition, some research libraries have invested in publishing and scholarly communication initiatives that target dissemination gaps for interdisciplinary scholars.

The escalation in interdisciplinarity in the academy has been particularly taxing for collection development, as budgets shrink and demand rises for access to specialized literature in emergent domains. Bibliometric approaches have been applied to identify new interdisciplinary intersections and guide changes in selection and acquisition and sometimes staffing as well (Witt & Rudasill 2010; Dilevko & Dali 2004). Collections have also been extended to include new genres of scholarly communication, such as gray literature and social media, considered to be endemic to emergent interdisciplinary work (Ehrlich & Carreño 2012). Improving access to emergent literatures is a related concern that requires innovation in visualization and browsing functions to transcend established disciplinary description standards (Condit Fagan & Mandernach 2014; Dilevko & Soglasnova 2013).

In response to the prevalence of collaborative research, some libraries have introduced new, outward-facing positions responsible for direct support of team research and interdisciplinary research centers, extending both the location and scope of library services on campus. Information professionals in these positions engage with interdisciplinary teams in situ, interacting in the research process in roles where information expertise can add value, such as project managers, data curators, grant writers, and sometimes research collaborators. Embedded librarianship is a promising approach as illustrated by the model implemented by the Taubman Health Sciences Library at the University of Michigan (Smith et al. 2014). Designed as a boundary-spanning unit within an interdisciplinary research center, three new positions exemplify the kind of contributions information professionals can offer the research enterprise: a bioinformationist specializing in tools and resources, outreach, and educational programming; a liaison librarian to coordinate with other research centers; and a translational position to consult on data management, systematic reviews, and meta-analyses. Embedded librarians are part of a more general shift toward dispersed, anticipatory, and holistic services that may ultimately transform how research libraries meet their mission in supporting access to information and production of new knowledge.

With digital data becoming highly valued resources for sharing and reuse across disciplines, libraries have had to develop new services to assist researchers faced with new open access and data management requirements by their funding agencies. Libraries are serving as partners with faculty in navigating the complex, global network of data repositories and the need to adhere to technical standards and requirements. They play a particularly important role for "long-tail" research communities, outside the realms of big data in big science, which tend to produce heterogeneous data and lack disciplinary data infrastructure. The cross-disciplinary, service-oriented vantage point of libraries is ideal for productively engaging in the "informatics impact" of data-intensive, interdisciplinary science (Van Reenen & Comerford 2012). Information services can extend well beyond access to collections and data services, to other social dimensions of the research process, such as navigating collaborations, publishing and tenure issues, use of language and application of methods across fields, and other boundary-crossing challenges faced during the career trajectory of interdisciplinary faculty.

In the system of scholarly communication, for example, the dominance of discipline-centric journals and limited number of well-defined interdisciplinary markets have deterred dissemination of interdisciplinary work (Weller 2011). Given sufficient support from the library and related campus units, interdisciplinary researchers have the potential to pioneer much-needed advances in dissemination and exchange of scholarship (Woolums 2012). Progress to date in library publishing units and scholarly communications offices at some universities has included investments in interdisciplinary publishing experiments, scholarly blogs, and other social media for research communities; developing digital thematic research collections; integrating data into journal publications; and disseminating machine-readable and multimedia publications. The distinctive niche of library programs in the ecosystem of scholarly publishing can incubate and possibly sustain specialized, less commercially viable interdisciplinary work on topics and in formats not accommodated by traditional publishers (Bonn & Furlough 2015).

30.5 Conclusion

The vision of a comprehensive, integrated information ecology motivated early information scientists such as Paul Otlet and Vannevar Bush, and it continues to capture the imagination and ingenuity of information researchers. The current digital information environment, however, is far from complete and unified. The distributed network of information resources on the Web is vast, complex, and much more ad hoc than the organized scholarly collections once held primarily by research libraries. Contemporary cyberinfrastructure initiatives are making headway, with significant investments in enabling interdisciplinary e-research through sharing of digital data and tools and supporting collaboration across domains (National Science Board 2005; National Science Foundation 2007; American Council of Learned Societies 2006; Lyall et al. 2015), while research communities that depend on these technologies advocate for true interdisciplinary communication through a "layered, agile, distributed and context-rich publication model" (van Harmelen et al. 2012).

In fact, interdisciplinarity is intensifying to the point where we should consider a future where it is no longer distinctive but rather the pervasive mode of research and knowledge production. Consider, for instance, that nearly 10 years ago one report on library service needs at the University of Minnesota (2006) found that among 50 participants across the social sciences and humanities "nearly every faculty member interviewed considered his or her work to be interdisciplinary" (p. 20). With pervasive interdisciplinarity, new questions come to the forefront about the possible imperative of disciplines as the intellectual backbone for scholarly production, as suggested by Jacobs (2014) in regard to academic programs. How essential are disciplinary distinctions in the work of gathering and synthesizing information for the "inter" processes integral to interdisciplinary research? Do disciplinary boundaries become obsolete or more critical as anchors for navigation and retrieval across domains? Some degree of scatter may in fact be fundamental to interdisciplinary progress, since information at the edges of a field is more diffuse and connective, preventing isolation of ideas within the core of a domain (Crane 1972; Chubin 1976). Conceivably, a state of hyperinterdisciplinarity could reduce disciplinary contours and work against the boundary functions of bridging and diffusion. For example, online search and discovery systems balance precision and recall in retrieval through operationalization of relevance. The positioning of information in the core or at the margins of a perceived domain is no doubt a strong factor in relevance judgments by people and has direct implications for engineering technical retrieval capabilities.

Current discovery systems excel at casting a wide net to gather information concurrently from an array of sources, and cross-disciplinary ontologies are increasingly employed to map content across domains for smoother digital access across fields. However, for synthesis of highly specialized knowledge, deep access to information within a domain, a collection, or a document is also vital. Complicating matters further, the original context of a scholarly product, be it a paper, a dataset, or a blog post, can be easily lost in a large aggregated information system or data repository, or through casual repurposing of digital content. Explicit documentation of the provenance of scholarly works and the relationships among digital variations, derivatives, and combinations has never been more critical or more difficult to capture and preserve. Representation of context and relationships are the linchpins, not just for discovering information resources across institutions, repositories, and disciplines but also for assuring the ability to interpret the meaning of content within its original intellectual context.

Growth, distribution, and change are the dominant information dynamics in the networked environment, and they are not inherently beneficial to interdisciplinarity. As networked information systems become more advanced, scholars will find it easier to draw from and make connections to other fields, and to place their research in a broader cross-disciplinary context. That facility may greatly accelerate the rate of exchange but not necessarily the veracity of knowledge integrated across disciplines. The greatest challenge ahead will not be navigating and retrieving information across disciplinary boundaries but rather sustaining the increasingly long and mutable paths back to our disciplinary intellectual foundations to assure meaning and validity in the new interdisciplinary knowledge we create.

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CHAPTER 31

COMPUTATION AND SIMULATION

JOHANNES LENHARD

QUANTIFYING things and their relationships counts as an important part of treating them scientifically; and processing quantities requires computation. Electronic computing devices have speeded up computation enormously, but taken as an isolated fact this is hardly relevant to interdisciplinarity. Computational approaches have distributed widely among many scientific disciplines—and are going on to penetrate our culture in more generally. The speed of computation alone, however, can hardly account for this fact. What makes computation highly relevant for an account of interdisciplinarity is the way in which electronic computing machines are embedded into a scientific-technological context.

"Simulation modeling" is perhaps the more appropriate term here, as it indicates that it is a special brand of scientific modeling. It stands for a way—or rather a variety of ways—of making use of computational resources in fields that are not of a mathematical nature. Computation and simulation (C&S) hence heavily influence a host of disciplines. This chapter argues, moreover, that C&S has acquired a high significance for interdisciplinarity.

The word "computer" was initially used for human workers, typically women, who were employed to carry through huge numbers of elementary calculations. This activity was replaced by machines—much in the vein of the replacement of human work skills by machine tools during the Industrial Revolution. At first analogue devices, like Vannevar Bush's differential analyzer, were used to solve specific classes of mathematical problems (Mindell 2002). During the 1940s and early 1950s digital computers were first developed. These two types of machine coexisted for a while, but eventually digital computers took over and became a synonym for "computer." One decisive reason for this was the establishment of computers not as tailor-made instruments for specific purposes, but as general-purpose machines—machines that can be instructed to do virtually everything that can be described in a formal way (the so-called Church-Turing thesis). This has had extraordinary implications. Simulation translates everything into digital information and uses computational algorithms to construct objects as diverse as airplanes, hurricanes, or social trends.

Simulation, too, has analogue precursors—mimicking models like flight simulators that worked with sophisticated arrangements of Bowden cables, and so forth, to create a model cockpit that for the novice pilot could feel like a real one (Rolfe and Staples 1988). Today,

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however, simulation is normally conceived of as digital computer simulation, and this is the sense in which it is used here.

Roughly in parallel to the development and spread of the computer, simulation has become established as a new means for knowledge production. The amount of computing power that has become available over the last decades is undoubtedly one reason for this development. Another reason is that simulation is an especially generic instrument, quickly convertible to different contexts of application. Computer simulation affects, and partly coproduces, the social, cognitive, and organizational spheres of science and technology—and even significant parts of broader contemporary culture. In particular, simulation practices involve the concept of interdisciplinarity in many (and partly new) ways.

The first part of this chapter introduces four phases of the historical development of C&S and discusses their relationship to interdisciplinarity. The second part explores aspects of the interdisciplinary dynamics of C&S, and the final outlook speculates about the potential hegemonic role of C&S.

31.1 Historical Development

We can distinguish four phases of C&S: a pioneering one lasting from 1940 to 1960; a phase of disciplinary specialization, roughly from 1960 to the 1980s; a third phase of ubiquitous diffusion from around 1985 onward; and finally, a new fourth phase since 2005 that is marked by an infrastructural turn. All phases are connected to interdisciplinarity in a different way.

31.1.1 Pioneering Phase, 1940–1960

Digital computer simulation emerged in the scientific-military complex of World War II. This first pioneering phase saw an interdisciplinary effort to establish C&S in the context of "big science." The period witnessed a number of interrelated technological innovations that make it hard to single out a linear story. The *First Draft of a Report on the EDVAC*, written by John von Neumann and based on ideas of many researchers (von Neumann 1945), can be seen as a founding document of the modern mainframe computer—a computing machine that can be programmed and has a serially working central processing unit. This achievement was based on a close encounter of engineers and mathematicians, disciplines that had not met regularly but did so in the context of war-related big science (Edwards 1996; Akera 2006). Funding increased rapidly, particularly in the United States, and consequently a great number of people got involved in research and development and also organizational issues. Progress in C&S happened in relatively small interdisciplinary groups that were highly interconnected, like those at the Moore School of Electrical Engineering at the University of Pennsylvania or at MIT; sometimes these groups were embedded in bigger and more hierarchically structured endeavors in computation like those in the Aberdeen Proving Ground (US) or Bletchley Park (UK).

Interestingly, basic simulation concepts and techniques were invented at the same time and in direct correspondence to anticipated growing resources for doing calculations.

Monte Carlo methods, their sibling Markov Chain Monte Carlo (MCMC), cellular automata, artificial neural networks, and finite difference methods all go back to this early phase (Metropolis 1980; Johnson 2004). The so-called Cybernetics Group is an example where scientists of very different disciplines tried to spell out the new possibilities of C&S. The Macy conferences of the 1940s and 1950s documented their highflying hopes for interdisciplinary achievements and even a new epoch of science that surrounded the computer (Heims 1991). The joint interest of cognitive scientists, engineers, mathematicians, and psychologists led to new fields of research like human–machine interaction (cybernetics) or artificial intelligence (on the latter, cf. Turing 1950 and the Dartmouth conference in 1956).

31.1.2 Disciplinary Specialization, 1960–1985

In the second historical phase electronic computation and computer simulation methods ceased to be extraordinary. The often ad hoc mixture of interdisciplinary teams located at the frontier of research that developed prototypes of machines changed into a professional—and often industrial—configuration of research and development. The famous early estimation that the potential demand of electronic computing machines would consist of only a handful worldwide was palpably disproved, and the computer became a commercial product. The icon of the commercial facet of this phase is IBM. Moreover, this icon also signaled the end of this phase, as the introduction of the personal computer by IBM in 1981 heralded the next phase, in which the influence of IBM became marginal.

The advance of computers still happened in interdisciplinary research teams, in the context of industry as well as, to a smaller extent, academia, and showed some continuity with the first historic phase. The military sector remained a significant source of money and interest, as steady progress was made with regard to decreasing size and increasing computational power. Importantly, the whole field underwent professionalization to a very high degree. One facet was the emergence of trained computer scientists who secured and stabilized the interdisciplinary mixtures of the pioneering phase.

Computer science, however, despite professionalization, was—and continues to be—a vaguely defined discipline. While computer science departments split off from mathematics departments in the early 1980s, the second generation of computer scientists were more commonly software engineers. It is still controversial whether computer science constitutes a discipline in its own right or is of an interdisciplinary nature (Mahoney 1992). A main reason for this is that the instrument itself, in particular the software, has become so complex. Hence it turned out to be unfeasible to draw an abstract picture of how computer models work or how the computer itself works—at least there is still no unanimity about it, and different viewpoints that favor abstract mathematical approaches versus practice-oriented engineering ones still vie with each other (MacKenzie 2001).

In this period expertise was distributed among hardware developers and software engineers: Standardized components began to foster exchangeability in terms of both instruments and people. The development of higher-level computer languages, like FORTRAN, which is still in use today, provides a particularly significant example. Information and computer science were established as scientific and engineering disciplines. In sum, a corona of specialized disciplines accompanied the further development of C&S during that phase, disciplines that divided labor and created subject matters of their own. They ranged from software engineering and linguistics to mathematics and materials science and addressed problems like creating semiconducting materials, developing a software language, or investigating the efficiency of algorithms.

While at this time C&S was becoming a more and more viable alternative approach in many scientific areas, it was still seen as a secondary option to more established and traditional methods of scientific research. Computation and simulation covered both parts of the scientific culture, what Hacking (1983) called representing and intervening. The socialization of researchers played a key role in the assignment of an inferior status to C&S compared with traditional approaches to science: the supposed inferiority of machine- and instrument-related work compared with theoretical skills was deeply ingrained in most disciplines. Also, the association of simulation with imitation bestowed on C&S a somewhat distanced or even deceptive character.

Beginning in the 1960s, a new generation of engineers and scientists used computer simulation more and more as a "scientific instrument," and oriented future research plans toward the possibilities that were suited to computational means. However, these groups remained a minority. Steadily, C&S acquired more connections to various fields of application—aptly symbolized by its common location in the basement of buildings—not the finest address, but a base technology for many. A clear indicator of the specialized and partly autonomous status of C&S is the emergence of journals and conferences devoted to it—such as the Winter Simulation Conference with its own series of proceedings. Also, a number of books were published that aimed to summarize and explain the specifics of C&S, prominently among them McLeod (1968), or Zeigler (1976). The C&S community was not centrally organized, though, and the actual application of C&S was much wider than reflected in the journals. So it remained an open and controversial issue whether C&S constitutes its own discipline or rather an interdisciplinary field.

31.1.3 Ubiquitous Diffusion: 1985 On

The third phase in the evolution of C&S is linked to the wide availability of smaller machines—personal computers, workstations, and networked architectures of them—that made C&S largely independent of "big science" and helped transform it into a virtually ubiquitous phenomenon. There is no exact starting point for this phase, but it is closely connected to the so-called PC Revolution that changed computers from a scarce resource into a highly available one. Computation and simulation left the somewhat restricted space of computationally intensive special sciences and gained ground in many areas of modern culture, from movies ("animation") to the Internet's "virtual reality." At the same time, C&S acquired a new status in the more restricted area of science and technology: From a professional but second-rank method during phase two it developed into an approach of equal rank, now openly accepted and widely hybridized with all sorts of traditional approaches and disciplines. Relying on C&S became a matter of course in many scientific disciplines. From the beginning, most of these fields, from computer animation to computational sciences of various types, perceived themselves as transforming existing disciplinary fields into interdisciplinary ones. Basically, an interdisciplinary mixture of computer science became embedded into a much wider system than in phase two. To speak in terms of the historian and sociologist of science Terry Shinn, C&S became a "generic instrument" (Shinn 2001; see also Küppers et al. 2006).

Standardization of hardware and software came with the PC revolution. Networked architectures of personal computers and workstations—which connect the workplace directly to local computing facilities—now became the norm. For a majority of working places, among the first things to get is network access for your computer. Of course, supercomputing machines still exist and remain important tools. However, the majority of scientific and technological research and applications run on relatively small machines. One should note that today's small machines are, due to Moore's law, as strong as supercomputers were not so long ago.

Applications in nonscientific contexts rely entirely on these smaller architectures. They are affordable to a wide audience of research groups, commercial firms, and the entertainment business. Not only are hardware components widely sold as commercial goods but also the system software has also been standardized so that, for instance, trained students can do the job of a system administrator at an academic research institute.

A spectrum of computational sciences appeared. Every classical field of natural science nowadays has one or more computational siblings, like computational fluid dynamics, or computational molecular biology, not to speak of engineering disciplines—computer-aided design is eliminating paper-and-pencil. Sociology, linguistics, and other branches of social sciences and humanities have embraced this development (Bynum & Moor 1998; see the *Journal for Artificial Societies and Social Simulation*). Furthermore, medicine, cognitive science, and neuroscience often rely crucially on C&S—examples are so abundant that any attempt of giving an exhaustive list seems forbidding.

Computational sciences emerged by the coalescence of C&S with formerly independent disciplines or without any disciplinary forerunner. Obviously these changes affect the configuration of the disciplines generally. This is true also for large parts of the engineering and design sciences. Computer-aided design, for instance, has changed from a somewhat exotic status at the end of phase two to a now everyday process—without even an alternative in many branches (cf. Turkle 2009). Last, but not least, the entertainment industry and large parts of the educational sector have been affected greatly by simulation and gaming. The entertainment sector based on C&S constitutes a multibillion-dollar industry; in 2008, for the first time, videogame software accounted for more than half the electronic entertainment media revenues in the global market. This does not imply that the military has lost influence; some researchers hold that military and entertainment sector have converged into one complex and are the driving force of C&S (Lenoir 2000).

These developments all came together and created a new, computer-based, decentralized type of interdisciplinarity. Whereas during phase two researchers and developers with different disciplinary expertise met in the (physical) vicinity of the computer, in phase three the maturing of C&S comes with a distribution of instruments, people, and expertise. Researchers of one kind rely on many elements and modules that others have provided: for instance, molecular biologists may use C&S models and plug-in software that have been developed in completely different areas. This effect of black-boxing—of using some device without detailed knowledge of its internal set-up—is well known from all kinds of instruments that have become established and widely used.

31.1.4 Infrastructural Turn, Around 2005

Any attempt to parse the recent and ongoing story about big data, eScience, crowd science, grid science, and their like is a tentative one. It may look outdated after a relatively short time span, dependent on what is going to happen. Nevertheless, the lack of foresight abilities should not prevent the attempt for a diagnosis.

This fourth phase is strongly linked to infrastructure, because the latter does not merely provide resources, but has come to be conceived as a subject matter of its own, defining problems in its own right. It is overlapping with the third phase, presenting more an additional mode than a replacement. This phase is simultaneously based on significant increases in connectivity (network), computational capacity, and the amount of data that are produced by instruments like satellites or DNA arrays. Together they create a tension between what can be called a *resource* and a *challenge* view. The first one sees this increase as an offer to science. It creates better facilities for scientific projects that had been impracticable before. The second approach focuses on infrastructure, but more as a challenge than a facilitator. The infrastructure *itself* becomes the foremost topic of research in C&S.

Let us illustrate both approaches by some examples. An iconic "resource" case is the initiative on grid computing of the National Center for Supercomputing Applications (NCSA). Its mission was "to solve the increasingly complex scientific problems of the 21st century" through "vast infrastructures" (NCSA 2004). Clearly, these problems are independently defined from the infrastructure and computing facilities; the latter just help to tackle them.

Another example is the Polymath project of the mathematician Timothy Gowers, which functioned as a chat room about mathematical problems posed by Gowers. This provided an opportunity for mathematicians to informally talk about problems, bringing together a group of people that would not have easily met otherwise. Gowers called the original problem discussion "one of the most exciting six weeks of my mathematical life" (Nielsen 2012, p. 2). Nielsen argues that the various contributors had complementary knowledge and that the online collaboration worked like a "cognitive tool."

A prominent example of the second "challenge" type is automated translation. This has become readily available via programs like the Google translator. The C&S approach behind it, the so-called statistically based translation (SBT), has become a showcase of big data, since SBT does away with finding general rules of grammar, and instead counts on scanning large amounts of known texts and translations for phrases similar to the one to be translated. Consequently, the result is not a grammatical sentence, but one whose meaning is conveyed relatively well. Halevy et al. (2009) claim that SBT shows how big data make the understanding of deeper (grammatical) structures dispensable.

A related claim is that data-intensive science adds a "Fourth Paradigm" (Hey et al. 2009) of science, which is characterized by its proponents as collaborative, networked, and data-driven—also praised as "eScience" (Gray 2009). Jim Gray, a pioneer of eScience, proposed that data-intensive science transforms scientific methods, replacing the older paradigms of theory, experiment, and simulation. Instead, Gray refers to an infrastructure for collecting and making accessible vast amounts of data.

To what extent these claims for a new scientific method are justified remains unclear. Perhaps the point boils down to the twofold insight that, first, an adequate infrastructure for large data traffic poses difficult scientific—and interdisciplinary—problems. Second, many practical tasks, such as translating a particular text, can be tackled as a problem of data analysis and without modeling the structure of the subject matter (grammar).

I close this section with an observation about the commercial character of the "challenge" viewpoint. Typically, the main proponents are researchers who work for big companies like Google or Microsoft. There, scientists of several disciplines work on generating commercial products, or consumer products. Consider the statement "The IT industry is building data centers, far beyond the financial scope of universities and national laboratories. . . . However, there are no clear examples of successful scientific applications of Clouds yet; making optimum use of such services will require some radical rethinking in the research community." (Bell et al. 2009, p. 1298). This statement makes graspable that science is expected to adapt to infrastructure and that economic thinking in a given framework of infrastructure plays an important role. "Optimal use" is the defining challenge, not finding the computational infrastructure for a given task.

31.2 Dynamics of Interdisciplinarity

The following sections investigate different dimensions in which the dynamics of interdisciplinarity is taking place.

31.2.1 Complexity, Experimentation, Visualization

Are the dynamics of C&S a driver or rather an outcome of other recent changes in science and science-related fields? A number of much-debated diagnoses identify fundamental transformations of research (Gibbons et al. 1994; Latour 1993; Ziman 2000) whose evaluation is not an issue here. However, there is basic agreement that science has increasingly entered real-life problems with all their complexities and that the strategies of simplification, idealization, and confinement have ceased to work properly, because these methods would have to reduce complexity, which in turn would destroy the crucial details of phenomena.

Two specific features of C&S highlight the recent drift into complexity: first, an experimental and explorative mode of research, and second the use of visualization. Complex computational models are often so complicated that researchers can hardly follow their operation in detail; work on them therefore has to proceed by experimentation (cf. Winsberg 2014, for philosophical literature). Researchers experiment on simulations by adapting parameters and submodules and running the simulations repeatedly. The typical goal is to compare and adapt the behavior of these tweaked models to the phenomena they should simulate. Such a practice goes back to the pioneering phase one but became full-fledged in phase three, because the exploratory nature of computational modeling is greatly enhanced by easy and cheap access to computational power. Now researchers work on computational models, whether they consider themselves experimentalists or theorists. "Working on" models mean exploring the relationships between input data and output data in order to produce verifiable predictions or better (that is, more accurate) models. With the mature desktop computer, model exploration became a key practice in scientific research, and not one limited to computational scientists, but rather one that is commonplace among most scientists and engineers.

This exploratory mode depends on researchers' ability to quickly assess the outputs of various models. Assessment of model outputs is especially feasible in visual, as opposed to numerical, forms. Visualization is also a feature of the desktop computing revolution, although one that did not emerge from scientific computing. Desktop computers, with their many different kinds of users, have been at the center of a series of changes in the visual display of information. From computer games to animation to Web pages, computers have grown to be devices focused on visual display. These extrascientific demands have created capacities critical to scientific uses—especially in three-dimensional display. Visualization in science has changed because of the ability of computers to generate images. These images are tremendously powerful; they carry information more efficiently than do tables of numerical outputs, as a result they yield compelling results—sometimes in misleading ways. Consequently, visualization reinforces the exploratory mode of scientific research, by making possible the quick uptake of results from computational models (Johnson & Lenhard 2011).

For a simulation to work properly two conditions are crucial: First, technical possibilities for display, feedback, and interaction need to be in place. The degree to which this first condition can be met rests itself on an interdisciplinary achievement. Second, C&S methods have to be guided adequately so that the performance of the resulting models or devices are actually good-enough imitations. This second condition depends heavily on the intended purpose, for example, when an endocrinological simulation counts as realistic, or when a simulated car crash can substitute a real one. Whatever the specific content of this condition is, its very specification rests on an interdisciplinary accomplishment—it is an interdisciplinary question of what determines a good imitation, and what characterizes a good performance. Hence, depending on the intended application, medical doctors, pilots, or other experienced specialists will typically participate in the development of a particular simulation. With increasing refinement of simulation technology, the interdisciplinary task grows as a more and more diverse range of aspects is simulated.

Consider the field of simulation and gaming that conceives itself as its own, crosscutting discipline that has an interdisciplinary nature (producing an appropriate virtual environment for the programmer is a highly interdisciplinary task). Many simulation games only work if the imitation is good enough for the players to be immersed into the simulation. Movements, body shape, language processing, and many more aspects are crucial for that. The recent renaming of a pertinent scientific journal in the field serves as illustration: *Simulation & Gaming: An International Journal of Theory, Practice, and Research* in 1995 changed to: *Simulation & Gaming: An Interdisciplinary Journal of Theory, Practice, and Research*.

31.2.2 "Research Technology" and the "Trading Zone"

A number of views exist that draw widely different pictures of the dynamics of C&S and especially its interdisciplinary and cultural significance. A main reason for this diversity is surely the heterogeneity of C&S itself that allows for various perspectives. The French philosopher Jean Baudrillard, for instance, aims at a broad panorama of culture and of the way reality, symbols, and society interact (Baudrillard 1998). He takes "simulacra" as a key notion to name the tendency to act in symbolically constructed worlds without real underpinning and connects this to simulation in particular. The philosopher of science Paul Humphreys, to give another instance, analyzes C&S from a science-based viewpoint. In particular, he identifies "computational templates" as a key for the dynamics of C&S, that is, pieces that code mathematical formulas and that can travel widely, with these formulas showing up in totally different contexts and disciplines (Humphreys 2004).

The analyses of Terry Shinn and Peter Galison take a middle ground in this spectrum and especially take into account the social aspects of the interdisciplinary dynamics of C&S. They subsume it under a broader framework and see these dynamics as an instantiation of what they call "research technology" (Shinn) and "trading zone" (Galison). These frameworks are of course different, but each captures essential aspects of the C&S revolution.

Shinn claims that four elements characterize research technologies. First they are produced by interstitial communities; that is, they do not arise from single institutional, disciplinary, or industrial problems or uses. Second, "the devices that research-technologists deal with are generic" (Shinn 2001, p. 9), meaning they are not designed to respond to any specific industrial or academic demand. Third, research technologies "generate novel ways of representing visually or otherwise events and empirical phenomena" (Shinn 2001, p. 9). Fourth, they are disembedded from their context of invention, a direct consequence of their general nature, becoming nonlocal to any one scientific community. Küppers et al. (2006) employ the concept of research technology to interpret C&S as "generic instrument" that allows usage in a large number of heterogeneous domains. The generic quality of C&S is key for its great economic success.

Shinn identifies a simulation-linked "lingua franca" as an important factor to bridge different disciplinary backgrounds and refers to Peter Galison's work on the concept of a "trading zone" (Galison 1996, 1997). In his article on the early history of the Monte Carlo method, Galison captures the interdisciplinary dynamics between the researchers as follows:

> Their common activity centered around the computer. More precisely, nuclear-weapons theorists transformed the nascent 'calculating machine," and in the process created alternative realities to which both theory and experiment bore uneasy ties. Grounded in statistics, game theory, sampling, and computer coding, these simulations constituted what I have been calling a "trading zone," an arena in which radically different activities could be locally, but not globally, coordinated. (Galison 1996, p. 119, original emphasis)

Galison's concept, like that of Shinn, embraces a strong social component and links inter- or transdisciplinarity to a C&S-related language. From this viewpoint, Galison describes the passage from the historical phase one to phase two (see above) as a transformation of language: "By the 1960's, what had been a pidgin had become a full-fledged creole: the language of a self-supporting subculture with enough structure and interest to support a research life without being an annex of another discipline" (Galison 1996, p. 153).

31.2.3 Simulations at the Edge

The population of simulation models always has had very complex exemplars, progressing at the edge of C&S technology. Furthermore, these simulation models have become objects of debate in a wider public and are of great relevance in the policy arena, hence C&S also inhabits the edge between science and policy. A famous early example in this respect is *Limits of Growth* (Meadows et al. 1972), a study commissioned by the Club of Rome for which Jay Forrester's Whirlwind computing project at MIT was operational (Akera 2006). This C&S-based study—and in particular its mission to make predictions for complex systems—received enormous publicity and introduced simulations as objects not only in science but also in the political arena. Today, climate simulations have inherited this role. They have triggered a flurry of analyses, typically in the field of science and technology studies (STS), that investigate how these models function, how researchers and politicians argue with them, and so forth (cf. Miller & Edwards 2001; Heymann & Kragh 2010, among others). This case exemplifies the potential usage of C&S-based models in different disciplinary contexts and even different sectors of society.

31.2.4 Network-Like Interdisciplinary Integration

The C&S-related dynamics of interdisciplinarity have developed over time, largely in parallel to the historical phases of C&S. Again, climate simulations can illustrate this. The historical origins of climate analysis are rooted in models of the circulation of the atmosphere—general circulation models (GCMs) that have been developed since the mid-1950s. The theoretical core of these models is built by the so-called fundamental equations, a system of partial differential equations from the physics of motion and thermodynamics. With the growing interest in climate change in the 1980s, a period of substantial growth of these models was inaugurated, because more and more facets of the climate system had to be included while aiming at a comprehensive picture. The growth included both the resolution of more subprocesses, such as the dynamics of aerosols in the atmosphere, and the addition of subprocesses in parameterized form, such as clouds, which are included via certain parameters that shall express the effects of clouds but not their entire internal dynamics.

One aspect of the development of more comprehensive models is of particular importance. A multitude of submodels had to be included into the atmospheric GCMs that had little to do with the theoretical physical basis of the atmospheric circulation, for example, ice cover, circulation of the oceans, or land use. Today, atmospheric GCMs—and with them physics as discipline—have lost their central place; coupled models entertain a deliberatively modular architecture and comprise a number of highly interactive submodels. These have been developed by groups of diverse disciplinary affiliations. They constantly interchange data during the runtime, but do not share a common theoretical framework. Thus, hierarchical integration around atmospheric GCMs has been replaced by a network-like integration of exchangeable modules. Küppers and Lenhard (2006) argue that the architecture of simulation models reflects a new style of interdisciplinary modeling. Edwards (2010) highlights the simultaneous relevance of infrastructure, C&S, and the social/political sphere.

These observations are not restricted to climate simulations, but rather exemplify a typical phase-three approach. The work of Merz (2006), for instance, shows quite similar developments in the organization of the particle collider at CERN, which is based on a complicated and extensive phase of simulation. Various kinds of distributed computing also illustrate this: So-called grid-computing is a recent issue that deals with the question of how to couple or even integrate various C&S resources at different locations. The central role of infrastructure has arguably given rise to a fourth phase in C&S, coming with a host of buzz words like grid computing, eScience, or big data (see section 31.1.4).

31.3 Conclusion

Simulation and computing will continue to change the face of science, engineering, and many facets of modern culture, driven by ongoing developments of all elements of C&S and by demands for highly complex models and applications. Hence any diagnosis of the future of C&S implies trying to hit a moving target and may become outdated quickly. A critical understanding of the technological nature of this instrument and its implications is still missing. Earlier accounts of the history of C&S still have to be adapted to the recent phases three and four. In particular, computer simulation often comes along with a distributed architecture, involving a multitude of disciplinary working researchers. Although some important discussions are going on already, the impact on type and organization of interdisciplinarity is not yet fully conceptualized.

Important unresolved questions concern the issue of validation: C&S is especially attractive when direct comparison with real phenomena is difficult or impossible for reasons of risk, cost, or time. But how should these simulations be validated? How is this actually done? It is not clear what the meaning of "validation" is or should be in this context (cf., for instance, the concerns of Joppa et al. 2013). At the same time, scientific methods and results usually claim to be valid (in some sense and to some degree).

Let me put forward a hypothesis: C&S might be on the way to becoming hegemonic in the sense that sciences, or relevant parts of them, are reorganizing so that they can take advantage of computer and network capacities. Computation and simulation, infrastructure, and interdisciplinarity would then be in a process of coproduction. This would make the question of validation much less pressing. Instead, a kind of self-vindicating dynamics would begin. Issues of C&S are turned into proper objects of science itself. Resorting to C&S then would not need a justification, it would just be the normal method. A typical question could then be the one mentioned above in section 31.1.4, when discussing phase four, namely the question of how a given computational infrastructure can be used in an optimal way. This kind of orientation lends itself to an economic paradigm. Instead of being a tool for interdisciplinarity, C&S would then become a motor that (co-) defines the concept of interdisciplinarity.

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CHAPTER 32

TAMING WICKEDNESS BY INTERDISCIPLINARY DESIGN

PRASAD BORADKAR

The word "design" is most frequently employed to refer to the action of planning and making (designing something), but it is also used to describe the end result or artifact of this action (a design). In other words, it indicates both—process and product. And here, by "product," I refer not only to things like toasters and cars but also to websites, interfaces for mobile phones, signage, interior spaces, buildings, gardens, and cities. Thus, the practice of design is central to a variety of well-established disciplines including, but not limited to architecture, automotive design, industrial design, fashion design, graphic design, and interior design.

32.1 Introduction

The etymological root of the word "design" can be traced back to *designare*, Latin for "to mark out" or "devise." Both marking out and devising signify an intent to create concepts that can be realized and materialized as objects. In other words, a designed object is "reified intention" (Mitcham 1994, p. 220). Other oft-quoted descriptions of design include "conception and planning of the artificial" (Buchanan 1990, p. 78) and "courses of action aimed at changing existing situations into preferred ones" (Simon 1996, p. 111). While most explanations of design tend to focus on the cognitive activity of generating ideas that eventually achieve tangible form, Simon's definition is much broader in its scope and shifts attention to external conditions. In addition, it suggests a motive for change that expects designers to know and specify what a "preferred situation" should be, thereby introducing an ethical and moral responsibility.

In recent years, design's charter has expanded beyond creating goods and services for the market to include tackling the enormous challenges posed by environmental pollution, income inequities, poor access to healthcare, lack of clean drinking water, and other problems of a global scale. Whether it is the design of small devices or large systems, designers have to consider issues of aesthetics, usability, ergonomics, safety, accessibility, marketability, affordability, profitability, manufacturability, functionality, and sustainability. By necessity

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therefore, design is interdisciplinary, and has to straddle craft and science, the humanities and the social sciences, as well as art and engineering in its practice and in its theory.

Design is generative and analytical; it demands creative thinking and critical problem solving. If such is the task of design, its practice necessitates that the practitioner and the theorist draw on knowledge that resides in disparate disciplines, and requires a type of thinking that can integrate multiple points of view. "Interdisciplinary skills are also particularly important for problem-solving in areas where there are a large number of variables together with high levels of uncertainty and risk. As Nobel Laureate Gunnar Myrdal commented 'problems do not come in disciplines'" (Gann & Salter 2001, p. 99).

If design's task, as Max Bill, rector of the influential Hochschule für Gestaltung in Ulm, once explained, is "to participate in the making of a new culture—from a spoon to a city" (Lindinger 1991, p. 10), its scope can be vast and its impact significant. And while the design of a spoon might be possible through the collaboration between a designer and a metalsmith, the planning of a city certainly is not possible without the involvement of a large number of experts including urban planners, city officials, transportation engineers, citizens, and other experts representing a variety of disciplines, points of view, and interests.

32.2 Design Practice and Theory

> No single definition of design, or branches of professionalized practice such as industrial or graphic design, adequately covers the diversity of ideas and methods gathered together under the label. Indeed, the variety of research reported in conference papers, journal articles, and books suggests that design continues to expand in its meanings and connections, revealing unexpected dimensions in practice as well as understanding.
>
> (Buchanan 1992, p. 5)

Most definitions of design refer primarily to design practice as manifest in the professions of architecture, industrial design, fashion design, and so forth. Designers involved in such activity often refer to their task as problem solving, and view their work as a response to opportunities and needs in the market identified by corporations, entrepreneurs, consumers, governments, and nonprofit organizations. The variety of domains in which designers operate and the range of outcomes they produce have made it difficult to establish a thorough taxonomy of design disciplines. In addition, as it evolves, design takes on new meanings, adopts new methodologies, addresses a broader range of problems, and redefines its scope, making it challenging to keep taxonomical structures current. If one imagines the totality of the built environment (from the spoon to the city) to be the domain of the designer, it can be broadly (and incompletely) classified into the domains and disciplines shown in Figure 32.1.

Though the divisions that exist among the various forms of design practice fracture the discipline, they do serve a critical role. "There are, of course, some good reasons why these practices were separated in the first place, and the issue is not to meld them all into a new, comprehensive profession that is at once everything and nothing" (Margolin 1989, p. 4). The design and manufacture of a hand-held device presents a set of challenges that are far different from those faced by an architect who is called on to oversee the design and construction

The Built Environment	The Design Discipline
The city and its environs	Urban Design, Landscape Architecture, Planning
Buildings and their interiors	Architecture, Interior Design, Exhibit Design, Set Design
Products	Product Design, Industrial Design, Toy Design, Transportation Design, Engineering Design
Communications and new media	Graphic Design, Visual Communication Design, Web Design, Interaction Design
Services and infrastructures	Service Design, Process Design, Experience Design, Systems Design

FIGURE 32.1 The domains and disciplines of design.

Topics of study	**Definition**
Design Technology	The study of the phenomena to be taken into account within a given area of design application
Design Praxiology	The study of the design techniques
Design Language	The study of the vocabulary, syntax and media for recording, devising, assessing and expressing design ideas in a given area
Design Taxonomy	The study of the classification of design phenomena
Design Metrology	The study of the measurement of design phenomena, with special emphasis on the means for ordering or comparing non-quantifiable phenomena
Design Axiology	The study of goodness or value in design phenomena, with special regard to the relations between technical, economic, moral and aesthetic values
Design Philosophy	The study of the language of discourse on moral principles in design
Design Epistemology	The study of the nature and validity of ways of knowing, believing and feeling in design
Design History	The study of what is the case, and how things came to be the way they are, in the design area
Design Pedagogy	The study of the priniciples and practice of education in the design area

FIGURE 32.2 Areas of work and research likely to be involved in the future development of design studies (Baynes et al. 1977).

of a hospital. Similarly, the design of a car interior demands the attention of transportation designers, ergonomists, mechanical engineers, materials experts and others, making it a vastly different challenge from the design of an archeological exhibition about Egypt's history, for example, which might involve archeologists, exhibition designers, curators, graphic designers, historians, and other experts. The level of granularity in the division of design labor encourages the development of domain-specific knowledge and gives designers the opportunity to refine their craft. However, it also presents the danger of narrow and compartmentalized thinking that can seriously limit design's impact. In order to generate holistic and comprehensive solutions to problems of the built environment, collaboration among disciplines is imperative.

In addition to the professional occupations, though, it is important to recognize the emergence of *design studies*, an interdisciplinary activity established to study design itself and develop a theory of practice. Bruce Archer, one of design's leading voices and advocate for the establishment of design studies, created a taxonomy outlining 10 topics within which further research would be needed to develop a theoretical body of domain knowledge.

Design studies seek to develop reflexive knowledge about design itself, especially in the areas of the history, theory, and criticism. Margolin (2002) advocates three key areas of research: "design methods" (understanding the process of design), "project-oriented research" (knowledge from practice), and "design as a cultural practice" (recognizing design's place in society) (2002, p. 251). As the labels imply, these are interdisciplinary areas of inquiry that depend on thorough engagement with such disciplines as philosophy, history, psychology, education, and anthropology for their development.

32.3 Design Education: A Historical Sketch

> Students who wish to become designers in the postindustrial knowledge economy will enter an inherently multidisciplinary profession. This profession involves a wide variety of professionals, including scientists (physical, biological, and social), engineers (industrial, civil, biological, genetic, electrical, and software), and managers, as well as the many kinds of artists and artisans now called designers.
>
> (Friedman 2000, p. 200)

While most of the academic coursework that students undertake in design programs is tightly circumscribed by the individual disciplines, there is a growing recognition of the need to create transdisciplinary opportunities. The formal tradition of incorporating multiple perspectives into design education can be traced to the Bauhaus, which in 1919 strove to create a unity between arts and the crafts. Walter Gropius, in the *Program of the Staatliche Bauhaus* published in 1919 in Weimar, summoned architects, painters, and sculptors to return to the crafts (Wingler 1969). This manifesto proclaimed that there was no essential difference between the artist and the craftsman, and proficiency in a handicraft was essential to every artist. Therefore, *Werkstatt* (workshop) instruction held supreme significance, and made up a large part of the students' quotidian learning activities. That the academic title of professor was supplanted by *Formmeister* (Master of Form) or *Werkmeister* (Master of Craft), and "student" by "journeyman" or "apprentice," authenticated Gropius's predilection for the artisanal approach to education.

By 1923, this mission had been redefined with an emphasis on technology. This shift in focus was exemplified in Gropius's lecture, "Art and Technology: A New Unity," when the Bauhaus embraced the ideals of mass production over craft-romanticism. They had decided to train not craftsmen but collaborators for industry, craft, and building. The workshops were renamed laboratories with the purpose of building prototypes of designs suitable for mass production. Toward the end of its life, the Bauhaus became an architectural school, and it was eventually closed in 1933.

In 1937, László Moholy-Nagy founded the New Bauhaus in Chicago to continue the initial Bauhaus mission by forming art, science, and technology as the three primary dimensions of design. Moholy-Nagy sought advice from the philosopher Charles Morris, who was then developing his theory of semiotics. Morris established coursework at the New Bauhaus in order to achieve "intellectual integration" among these three key pillars of design. "Morris considered the design act to be a kind of semiosis, and he drew a parallel between the syntactic, the semantic, and the pragmatic dimensions of a sign and, respectively, the artistic, the scientific, and the technological dimensions of design" (Findeli 2001, p. 7). Though these theories did not take root at that time, the attempt does demonstrate Moholy-Nagy's desire to introduce philosophical and linguistic concepts in design education. The New Bauhaus, which later merged with the Illinois Institute of Technology, continues to function today as the Institute of Design.

The Hochschule für Gestaltung (HfG), founded in 1951 in the city of Ulm in Germany, expanded the Bauhaus vision and outlined design's task as participating in the making of a new culture. Tomás Maldonado, who led the school from 1957 for a period of 10 years, suggested a more rigorous interdisciplinary education that included social psychology, sociology, anthropology, cultural history, and perception theory. The arts were no longer considered a critical foundation for design, and there was a heavier emphasis on developing a stronger scientific basis. Maldonado was interested in developing scientific design methodology and turned to several new disciplines emerging at that time: "cybernetics, information theory, systems theory, semiotics, ergonomics" (Maldonado 1991, p. 223). Though these disciplines were not thoroughly integrated into the curriculum, engaging them allowed Maldonado and the Ulm school to investigate and develop design's own scientific base. This school, which eventually closed in 1968, has been singled out as having influenced design pedagogy all over the world.

The three schools—Bauhaus, New Bauhaus, and HfG—developed interdisciplinary curricula around three primary concepts: art, science, and technology. As design itself has evolved, design education has extended its interdisciplinarity beyond these three to include new disciplines. At the undergraduate level, most programs require students to take courses in the natural sciences, social sciences, and humanities (mathematics, physics, psychology, etc.) as a part of their general studies requirements. In addition, design programs also encourage or require courses in marketing, economics, anthropology, and so forth.

However, this does not qualify as transdisciplinary design education, and therefore several design programs have set up team-based learning environments where students from a variety of disciplines (frequently business, engineering, and anthropology) work together on projects. At the graduate level, design programs exhibit a higher level of transdisciplinarity, and it is not uncommon to find thesis and dissertation projects that critically engage several disciplines. Today, with varying degrees of integration, several departments and schools of design have partnered with programs in business, engineering, and the social sciences across campus and at times across universities. Arizona State University, Art Center College of Design, Carnegie Mellon University, Illinois Institute of Technology, Rhode Island School of Design, Stanford University, and the University of Cincinnati are but a few examples of academic programs actively engaged in interdisciplinary design education.

32.4 Interdisciplinarity in Design

The process by which the tangible and intangible things we live with come into being varies to a certain extent across the design disciplines, but it is typically conducted in cross-functional teams that include, in addition to the designers, engineers, market researchers, financiers, manufacturers, sales personnel, retailers, and other experts. In some cases, domain knowledge specialists are invited to participate to provide expertise particular to the project at hand. For instance, if the design project is the creation of new surgical tools, the team might include surgeons; if it is a new suspension bridge, it might have specialized structural engineers on staff; if it involves a new park for a city, zoning experts might participate as well.

Design can be described as an integrative discipline that resides at "the intersection of several large fields" (Friedman 2000). For Friedman, the natural sciences, humanities, and liberal arts as well as the social and behavioral sciences constitute the "Domains of Theory" while the human professions and services, creative and applied arts, and technology and engineering make up the "Domains of Practice and Application." However, classifying these domains on the basis of theory and practice presents problems; just as there are theories of engineering, there is application in the humanities. These disciplines should instead be conceived of as contiguous areas of study so as to demonstrate the interaction among them.

Figure 32.3 represents a model where design problems can be mapped out on the basis of engagement with other disciplines. The domain map of the design project therefore takes form on the basis of the nature of the problem and the disciplines required to be involved.

Mitcham (1994) has classified design into two broad categories—engineering design and artistic design; the former driven by performance specifications and the latter by form; the first by efficiency and the second by beauty. Engineering design uses physics and mathematics in visualizing its material outcomes, and artistic design relies on the senses and intuition in creating its results. However, with growing interdisciplinarity and the emergence of new subdisciplines within design, the boundaries of such classifications become blurred. For instance, Web and app designers create graphic user interfaces that determine the aesthetic character of a website or the interface of a smartphone (a form of artistic design), but

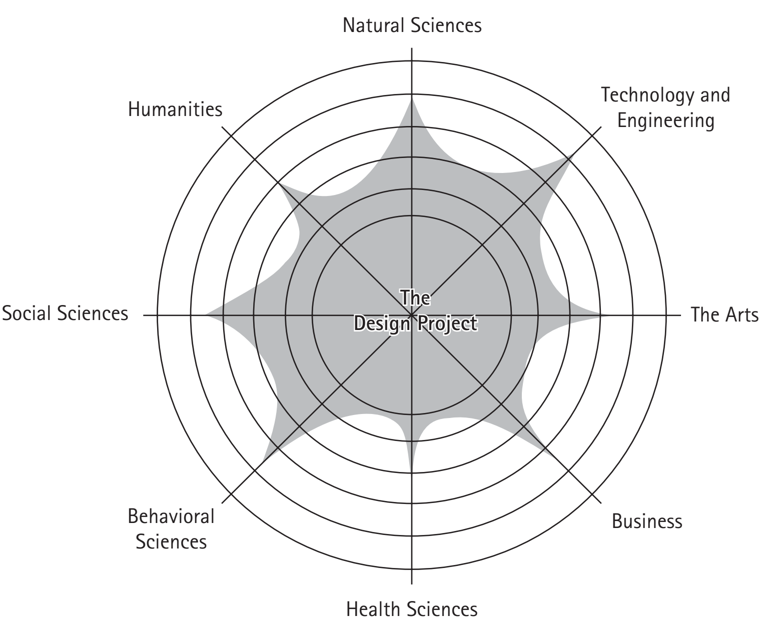

FIGURE 32.3 Domain map of a transdisciplinary design project.

many of them are also required to know some computer programming (a form of engineering design) in order to make the designs functional.

"Design is partly rational and cognitive, and partly irrational, emotive, intuitive, and noncognitive. It is rational to the extent that there is conscious understanding of the laws of nature; it is irrational to the extent that the sciences have not yet succeeded in revealing the laws of complex phenomena" (Buchanan 1995, p. 50). Most designers do not see their practice as purely artistic; although imparting beauty to everyday objects is certainly of importance, the agenda for design also includes solving problems that can improve people's lives and minimize impacts on the environment. In other words, engineering and artistic work are both central to design and not easily separable.

Scholars in design studies have sought to demonstrate that design possesses components that are unique and distinct from other disciplines (Friedman 2000; Cross 2002). "The underlying axiom of this discipline [of design] is that there are forms of knowledge and ways of knowing that are special to the awareness and ability of a designer, and independent of the different professional domains of design practice" (Cross 2006, p. 100). In other words, regardless of the object (building, garden, signage, app, etc.) being designed, designers follow a certain set of cognitive and physical processes that are unique to the discipline.

Cross describes design's unique activities as "designerly ways of knowing, acting and thinking" (Cross 2001). Multidisciplinarity, interdisciplinarity, and transdisciplinarity too can be described as three related yet distinct forms of knowing, acting, and thinking. As Klein explains in chapter 3 of this volume, these three terms "constitute a core vocabulary for understanding both the genus of interdisciplinarity and individual species within the general classification." These three terms also represent varying levels of integration among disciplines. While multidisciplinarity might signify a mere juxtaposition of several disciplines aligned to tackle a specific problem, transdisciplinarity refers to the transcending of disciplines in developing transformative solutions to complex societal problems. "Multidisciplinarity signifies the juxtaposition of disciplines. It is essentially additive, not integrative . . . The participating disciplines are neither changed nor enriched, and the lack of 'a well-defined matrix' of interactions means disciplinary relationships are likely to be limited and transitory" (Klein 1990, p. 56).

Generally speaking, in multidisciplinary projects, experts from several disciplines are involved, but their work may not always intersect. In such situations the problem may be segmented into smaller components that can then be appropriately handled by single disciplines. On the other hand, interdisciplinarity refers to situations where the knowledge and tools of one discipline inform, influence, and redirect the results of another. Much more disruptive and difficult to manage, engagement of this nature typically signals a destruction of disciplinary boundaries with the hope of generating new knowledge that would be impossible to produce by a single discipline.

Klein's descriptions of the various forms and degrees of engagement among disciplines can be applied to design practice as well as design studies. Design practice can be described as Klein's "trans-sector transdisciplinary problem solving," where the emphasis is on the "research questions and practices, not the disciplines." The process of new product development, where several disciplinary experts work together, frequently along with potential consumers, falls under this form of interdisciplinarity. Design studies, on the other hand, fits the model Klein labels "critical interdisciplinarity." This form of interdisciplinarity questions and challenges dominant structures of knowledge, and can therefore be transformative. It is in interrogating the rules set up by disciplines that critically interdisciplinary work blurs the boundaries between them. “Critical interdisciplinarity seeks to take the effort involved in mastering or going deep into any one discipline and spread it over a number of disciplines, going just as deep in a discipline as is necessary or appropriate to grasp the essentials” (Frodeman & Mitcham 2005, p. 513). In this process of engaging other disciplines, design can enrich itself with new points of view and more holistic conceptions of its process and products. And armed with this knowledge, designers might be better equipped to create products and services that are a lot more appropriate to their cultural contexts of use.

However, managing complex projects through interdisciplinarity teamwork is not easy. “This is the challenge for design research—to construct a way of conversing about design that is at the same time both interdisciplinary and disciplined. It is the paradoxical task of creating an interdisciplinary discipline. This discipline seeks to develop domain-independent approaches to theory and research in design” (Cross 2006, p. 100).

32.5 The Size, Scale, and Scope of Design Problems

Contemporary design practice is conducted in a world that is globally more connected, technologically more complex, and economically more intricate than it has ever been before. “The scale, penetration, and velocity of global capital have all grown significantly in the last few decades of this century” (Appadurai 2001, p. 18). The complexity engendered by these global capital flows is expected only to increase in the future, complicating design’s task even further. In response to these impending developments, design has already started to reimagine its scope. New conceptions of design now define its charter as the development of systems rather than single artifacts. There is recognition that designers need to consider global needs rather than individual wants. New design thinking emphasizes concerns of social equity and environmental responsibility, pushing design’s purview beyond its historical fixation on form. It is now also commonly accepted that design alone cannot solve these problems in isolation. The sheer complexity of these issues warrants deep engagement with other disciplines.

“The kinds of problems planners deal with—societal problems—are inherently different from the problems that scientists and perhaps some classes of engineers deal with. Planning problems are inherently wicked” (Rittel & Webber 1973, p. 160). One can argue that, in general, design (construed broadly to include city planning that the authors refer to) is often called on to tackle problems that are wicked, and that they require new methodologies to tame them. Such problems are difficult to formulate; they do not have right or wrong solutions; they do not have a logical end; and they are often symptoms of other problems.

The complexity and wickedness of these problems makes it impossible for any single discipline to be able to plan and implement solutions. In such situations, one mechanism by which to devise and deliver comprehensive solutions is through an intense and integrated collaboration among disciplines. And it is critical that problems taken on are not merely parceled into smaller components to be handled by individual disciplines but addressed in a highly integrated and transdisciplinary manner. “Transdisciplinary approaches are far more comprehensive in the scope and vision . . . Whereas 'interdisciplinary' signifies the synthesis of two or more disciplines, establishing a new method of discourse, 'transdisciplinarity' signifies the interconnectedness of all aspects of reality, transcending the dynamic of a dialectical synthesis to grasp the total dynamics of reality as a whole" (Klein 1990, p. 66).

The healthcare system in the United States, for example, presents a series of wicked problems. Take the issue of designing an effective patient transfer system for a hospital. Patients are generally transported between ambulances, emergency rooms, waiting rooms, laboratories, surgical wards, and pharmacies and using gurneys, stretchers, rolling beds, wheelchairs, lifts, hoists, and other devices. While being transferred, they are often hooked up to IV poles, oxygen tanks, or vitals monitors, and the transfers might involve, in addition to the patients themselves, nurses, nurses' aides, family members, social workers, and paramedics. Healthcare workers moving patients from one position (reclining in a bed) to another (sitting in a wheelchair) often hurt their backs, and research shows that nurses experience more injuries on the job than any other professionals. This has led to lost work, reduced pay, and workers' compensation claims, which become financial burdens for healthcare workers and hospitals. In addition, the problems posed by the growing rate of obesity and the increasing average age of nurses pose additional difficulties for hospital personnel who might have to move bariatric patients (those weighing more than 152 kg).

A patient transfer system will not only have to handle the problems listed above, but it will need to be cost-effective, able to accommodate patients who represent a wide range of body types and cultural backgrounds, easy to install, effortless to use, and above all, safe for patients and healthcare professionals. And unless it is able to adapt to existing as well as new hospital buildings, it will not be compelling enough to hospital administrators and purchasing departments. This problem is difficult to understand thoroughly: It possesses no single right, wrong, or objectively perfect solution; and it lacks finite and reliable evaluative criteria. It is clear that developing such a system would need to involve teams of hospital staff, healthcare workers (nurses, nurses' aides, paramedics, ambulance drivers), engineers, product designers, and marketing professionals, all working to inform and transform each other's thinking. This is merely one example of design's wicked problems that demand transdisciplinary efforts.

32.6 Taming Wicked Problems by Design

For Rittel, design's wicked problems are also ill-behaved because they frustrate the designers' efforts of wanting to create and follow a clear pathway to the solution from analysis to synthesis (Rittel 1971). In addition, solutions developed to tame wicked problems are difficult to evaluate, and it is difficult for designers to know whether to continue the process of searching for better solutions. While not all problems that designers tackle behave so badly, there are several, especially in the healthcare and transportation industries, that certainly do. Buchanan argues that design problems are wicked because "design has no special subject matter of its own apart from what a designer conceives it to be" (Buchanan 1992, p. 16). Designers tackle problems from a variety of domains, and the products of their labor range from paper clips to airplanes. For example, while a biologist may focus his or her life's scientific efforts on the narrow and highly specialized examination of butterfly coloration, an industrial designer may be called on to handle the unique problems of the creation of a car, a guitar, or a chair within the span of a few months. The domain knowledge required to practice design needs to be abstract enough to be applicable in a variety of contexts, while being specific enough to appropriately address the challenges at hand. And, the difficulty in being able to develop content expertise in several domains makes it even more attractive to engage disciplines that possess deep knowledge in those topical areas.

If design problems pose a unique set of challenges, designers need a unique set of tools with which to tackle them. Brainstorming, mind mapping, visualization, prototyping, storyboarding, scenario development, and so forth, are some of the commonly used methods in design praxis. However, while these methods can help with discrete segments of the problems, they do not serve as overarching strategies for taming or coping with wickedness. Roberts (2000) classifies problems as simple, complex, and wicked, and offers three unique coping strategies that she titles *authoritative, competitive*, and *collaborative.* She cautions that no single approach can present itself as a panacea, and decisions about selecting the most appropriate strategy will depend on the specificity of the problem. Authoritative strategies are recommended when a few key stakeholders are in positions of power in the problem-solving group, competitive strategies work best when power is dispersed and contested, and collaborative strategies serve well in the remaining situations (Figure 32.4).

There is no question that the design process—whether played out in small and medium-sized design consultancies or in large corporations—does involve power hierarchies and disputes among stakeholders (as well as disciplines). While authoritative or competitive strategies might lend themselves to simple problems that involve few stakeholders or small projects that can be quickly executed, it is the collaborative strategy that can work best for design's wicked problems. Collaboration offers the benefits of shared costs, the possibility of more comprehensive solutions, and better problem prediction.

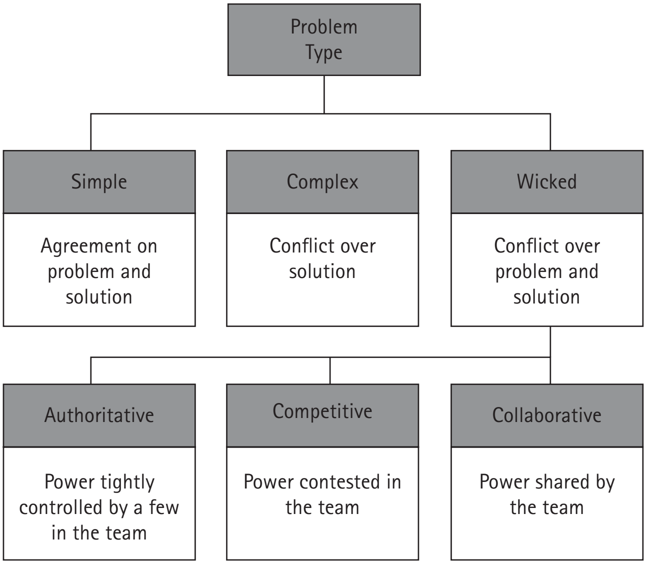

FIGURE 32.4 Coping strategies for wicked problems (developed from Roberts 2001).

32.7 Design Futuring

"In our endeavour to sustain ourselves in the short term we collectively act in destructive ways towards the very things we and all other beings fundamentally depend on. Such long-standing and still growing 'defuturing' needs halting and countering" (Fry 2008, p. 22). Defuturing, or taking the future away, is how Fry defines what humans have done and continue to do in making this world increasingly more unsustainable, socially and environmentally. Practices of design are certainly to be held responsible for this condition of unsustainability that has generated friction among our social, technological, and natural worlds. Instead of creating Simon's "preferred situations" we have done the opposite, and in the process erected a vast number of wicked problems (such as loss of biodiversity, species extinction, global poverty, income inequities, environmental pollution, and so on).

Fry suggests that we should be engaged in "remaking our own world" (Fry 2008, p. 249) if we are to tackle these problems of unsustainability. In order to do so, we will need to think big, think creatively, and think in transdisciplinary teams. Educational programs will need to prepare students with the skills and tools they can use in their professional careers to be able to tackle these issues. "But if knowledge is to be genuinely interdisciplinary, it needs to do more than simply reach across campus. . . . Our academic research portfolio must include an account of how to effectively integrate knowledge within the decision-making context faced by governments, businesspeople, and citizens" (Frodeman & Mitcham 2005, p. 513).

It is clear that active participation from a large number and diversity of stakeholders is critical to doing transdisciplinary design in practice and teaching it at the university. "The concept of superimposing various disciplines to address the problem or project in question could spawn a new hybrid category of design activity, which will emancipate itself from traditional disciplinary concepts" (Meurer 2001, pp. 52–53). This superimposition can be effective in design praxis and in design studies only if the boundaries among the overlapping disciplines can be made porous through truly integrated transdisciplinarity. Over the years, design's function has evolved from a craft-based practice of creating artifacts to the planning of complex systems. The collaborative strategy that transdisciplinarity brings to problem solving can help deal with the complexity of design problems. However, the highest possible level of integration among disciplines is necessary for this strategy to be truly effective. Only thus can society's wicked problems be tamed.

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PART VI

INSTITUTIONALIZING INTER- AND TRANSDISCIPLINARITY

CHAPTER 33

INTERDISCIPLINARITY AND THE INSTITUTIONAL CONTEXT OF KNOWLEDGE IN THE AMERICAN RESEARCH UNIVERSITY

MICHAEL M. CROW AND WILLIAM B. DABARS

The American research university emerged in the late nineteenth century during an era that witnessed the consolidation of many of the modern academic disciplines. Despite broad consensus regarding the imperative for inter- and transdisciplinary approaches to inquiry, twenty-first-century academic culture remains defined by the organization and practices established by this set of historically determined institutions. Even as interdisciplinary collaboration flourishes in the contemporary academy, the dominant structural characteristic of academic organization remains the discipline. Disciplinary acculturation defines academic culture, just as the traditional correlation between disciplines and departments persists as the basis for academic organization. Such disciplinary partitioning represents one of the most critical impediments—or design limitations—to the further evolution of the American research university.

This chapter focuses on the accommodation of interdisciplinarity within the American research university. Inasmuch as interdisciplinary teaching and research are widely acknowledged to be critical to the advancement of knowledge, finding the appropriate framework for interdisciplinarity represents a key dimension in the evolution of this institutional model. Because the impetus to advance new knowledge distinguishes the research university from other institutional types in American higher education, our assessment underscores the reflexive nature of the relationship between knowledge and its institutional context. The implications of this interrelationship are too often dismissed by academic culture as merely perfunctory administrative concerns (Crow & Dabars 2015).[1]

[1] This chapter contains revised passages from our coauthored book, *Designing the New American University* (Baltimore: Johns Hopkins University Press, 2015). The discussion of interdisciplinarity in this source contained revised passages from texts we have either coauthored or authored singly,

Crow, M. M. and Dabars, W. B., *Interdisciplinarity and the Institutional Context of Knowledge in the American Research University.* In: *The Oxford Handbook of Interdisciplinarity, Second Edition.* Edited by Robert Frodeman, Julie Thompson Klein, and Roberto C. S. Pacheco: Oxford University Press (2017).
DOI 10.1093/oxfordhb/9780198733522.013.38

33.1 The Disciplinary Entrenchment of the American Research University

A basic prerequisite for cutting-edge knowledge production is mutual intelligibility across academic disciplines and interdisciplinary fields. But as simultaneously epistemological, administrative, and sociocultural modes of organization (Wallerstein 2003), disciplines are deeply embedded in academic culture and structure institutional frameworks, as well as mediate knowledge production and diffusion. "All arts and sciences faculties contain more or less the same list of departments," observes the sociologist Andrew Abbott. Despite the momentum of interdisciplinary scholarship and varying degrees of academic reconfiguration, disciplinary departments persist as the "essential and irreplaceable building blocks" of American colleges and universities. Since being consolidated into the broad contours of their present-day configuration during the final decades of the nineteenth century, the department-based disciplinary system has remained "uniquely powerful and powerfully unique" (2001, pp. 126–128).

Ubiquitous calls for interdisciplinary collaboration notwithstanding, the tacit assumption in academic culture is that institutional frameworks have already been optimally configured to facilitate both the discovery and dissemination of knowledge. Despite insight into the social nature of knowledge production from such figures as Thomas Kuhn, Robert K. Merton, Michael Polanyi, Stephen Toulmin, and, more recently, Richard Rorty and Jürgen Habermas, the institutional context for knowledge production remains insufficiently explored. The concept of "structuration" proposed by Anthony Giddens suggests the extent to which knowledge production is determined by the "situated activities of human agents" (1984, p. 25; Cook & Brown 1999, p. 399n8). As the organizational theorists John Seely Brown et al. observe, "Knowledge is situated, being in part a product of the activity, context, and culture in which it is developed and used" (1989, p. 33). Elsewhere, Brown and Duguid note the corollary: "In a society that attaches particular value to 'abstract knowledge,' the details of practice have come to be seen as nonessential, unimportant, and easily developed once the relevant abstractions have been grasped" (1991, p. 40).

Effective interdisciplinary collaboration requires an optimally configured institutional framework as well as an academic culture conducive to innovation. Jonathan Cole thus characterizes one of the primary objectives of institutional design: "Almost all truly distinguished universities create a seamless web of cognitive influence among the individual disciplines that affects the quality of the whole" (2009, p. 5). Because structure mediates knowledge production, institutions that operate on the frontiers of knowledge must continuously

including the dissertation by William Dabars, "Disciplinarity and Interdisciplinarity: Rhetoric and Context in the American Research University" (University of California, Los Angeles, 2008), which in turn had informed sections of our coauthored book chapters "Interdisciplinarity as a Design Problem: Toward Mutual Intelligibility among Academic Disciplines in the American Research University," which appeared in *Enhancing Communication and Collaboration in Interdisciplinary Research*, edited by Michael O'Rourke et al. (Los Angeles: Sage, 2013), and "Toward Interdisciplinarity by Design in the American Research University," which appeared in *University Experiments in Interdisciplinarity: Obstacles and Opportunities*, edited by Peter Weingart and Britta Padberg (Bielefeld: Transcript Verlag, 2014).

recalibrate their frameworks to accommodate what Alan Wilson terms the evolving "knowledge space." In Wilson's estimation, universities are moving too slowly to maintain pace with the transformation in knowledge, referring in large part to the groundswell of interdisciplinarity (2010, pp. 8–39). These institutions also lag in their accommodation of the varied new forms of knowledge production generated throughout society.

Institutional design thus refers to the reconceptualization and recalibration of the organization, operations, and practices of knowledge enterprises such as research universities. Any institutional platform is the product of a sequence of decisions that determine its structure and functions, the conceptualization of which may be termed the design process. Institutional design must never be merely arbitrary, nor is its critique mere quibbling over a bureaucratic substratum that undergirds epistemological superstructures. This sense of design is implicit in the quest of modern science, beginning with Bacon and Descartes, to create a "community well designed for the attainment of epistemic goals," as Philip Kitcher observes. This view highlights the contingent situatedness of knowledge production—that the seemingly self-evident question "How should inquiry be organized so as to fulfill its proper function?" is always dependent on context (2001, pp. 109, 113). With reference to the development of scientific research in the early American republic, the historian A. Hunter Dupree underscores this point with particular eloquence: "For science is not often the sudden blossoming of the flower of genius, even in the soil of freedom. It is a group activity carried on by limited and fallible men, and much of their effectiveness stems from their organization and the continuity and flexibility of their institutional arrangements" (1986, p. 9).

33.2 Overcoming Disciplinary Entrenchment

The lack of adaptive capacity in the institutional accommodation of interdisciplinary knowledge production is nowhere more evident than in the posture of research universities when confronted by challenges on the scale of global climate change, air and water pollution, overpopulation, hunger and poverty, extinction of species, exhaustion of natural resources, and destruction of ecosystems. The National Academies report *Facilitating Interdisciplinary Research* underscores the connection between interdisciplinary collaboration and applied research initiatives that often engage large-scale team efforts to address complex and intractable problems. The report envisions "scientists, engineers, social scientists, and humanists . . . addressing complex problems that must be attacked simultaneously with deep knowledge from different perspectives" (CFIR 2005, p. 17).

The recommendations of the report are pertinent to institutional design efforts to accommodate interdisciplinarity. For instance, new structural models are essential to "stimulate new modes of inquiry and break down the conceptual and institutional barriers to interdisciplinary research that could yield significant benefits to science and society." The report also recommends "substantial alteration of the traditional academic structures or even replacement with new structures and models to reduce barriers" to interdisciplinarity. New models are essential because "prevailing academic cultures and structures tend to replicate existing areas of expertise, reward individual effort rather than collaborative work, limit hiring input to a single department in a single school or college, and limit incentives and rewards for interdisciplinary and collaborative work." The report points out that academic careers have historically been forged along disciplinary lines, as disciplinary affiliation defines social organization to such an extent that interdisciplinarians often find recognition among peers difficult. No less challenging is recognition by professional associations, business and industry, and most importantly, federal agencies, which in the estimation of the committee remain resistant to interdisciplinarity (CFIR 2005, pp. ix–xi, 6, 100, 149–170).

While the terms "interdisciplinarity" and "transdisciplinarity" appear in this chapter more or less interchangeably, both knowledge production itself and the reconceptualizing of institutions as complex adaptive knowledge enterprises are more appropriately designated *transdisciplinary*, in that such efforts seek to advance collaboration among universities, business and industry, and government. As Robert Frodeman observes, "More accurate usage would have 'interdisciplinarity' denote changes needed within the academy, 'transdisciplinarity' to efforts to move beyond university walls and toward the co-production of knowledge between academic and non-academic actors." When coproduced and coordinated transinstitutionally, coevaluation of knowledge by actors beyond the academy complements the process of peer review (2014, p. 61). Peter Weingart makes the similar point that because the university has "lost its monopoly" as the sole institutional locus of knowledge production, the criteria for the evaluation of quality in transdisciplinary research become social, political, and economic, as well as disciplinary (2010, p. 12).

Collaboration beyond the academy is implicit in the concept of convergence, which integrates the life sciences, physical sciences, mathematical and computational sciences, and fields of engineering, and embraces the social and behavioral sciences and arts and humanities. As formulated by a committee convened by the National Research Council, convergence engenders "comprehensive synthetic frameworks that merge areas of knowledge from multiple fields to address specific challenges." Implicit is not only the "convergence of the subsets of expertise necessary to address a set of research problems" but also the "formation of the web of partnerships involved in supporting such scientific investigations and enabling the resulting advances to be translated into new forms of innovation and new products" (2014, p. 17). Collaboration across transdisciplinary, transinstitutional, and transnational frameworks has the potential to advance knowledge production and innovation in real time and on the scale necessary for the attainment of desired social and economic outcomes.

The "triple helix" model of university-industry-government interaction described by Henry Etzkowitz epitomizes collaborative innovation. The triple helix comprises intersecting knowledge networks that leverage input from diverse multidisciplinary perspectives. In this context Etzkowitz elaborates on the "radical epistemological transformation" (2008, p. 141) ongoing in science, from disciplinary research that Michael Gibbons and colleagues termed Mode 1 to collaborative and applied research termed Mode 2 (Gibbons et al. 1994):

> The old paradigm of scientific discovery ('Mode 1')—characterized by the hegemony of theoretical or, at any rate, experimental science; by an internally-driven taxonomy of disciplines; and by the autonomy of scientists and their host institutions, the universities—was being superseded by a new paradigm of knowledge production ('Mode 2'), which was socially distributed, application-oriented, trans-disciplinary, and subject to multiple accountabilities. (Nowotny, Scott, and Gibbons 2003, p. 179)

Etzkowitz underscores the important point that the Mode 2 paradigm, which embraces both fundamental and applied research, represents the foundational platform for science institutionalized during its formative period in the early modern era (2008, pp. 141–142).

Corollary to the belief that the institutional structure of the university has already been optimally configured is the assumption that scholarship is primarily an individual endeavor, and that optimal outcomes naturally emerge from the amalgamation of individual efforts. Entrenchment in discipline-based departments mirrors an academic culture that prizes individualism over teamwork and the discovery of specialized knowledge over problem-based collaboration. Our competitive culture values the individual over the group, and because academia places greater value on the discovery of new knowledge by individual scientists, less prestige attaches to collaborative endeavors that target real-world problems. The same is true for team participation in projects that advance knowledge through assimilation, synthesis, implementation, and application. But without coordination and strategic collaboration, ad hoc aggregation of individual endeavors often fails to transcend the inevitable limitations of an isolated investigator. As Cook and Brown frame the dilemma: "Not every action by a human collective can be meaningfully or usefully reduced to an account of actions taken by the individuals in them" (1999, p. 399).

The institutional design of universities is fraught with the potential for misalignments between disciplinary factions. Reorganizing the university to facilitate interdisciplinary collaboration offers the potential to reveal new paradigms for knowledge production and application. Novel interdisciplinary configurations represent institutional experiments that can recalibrate the course of inquiry and enhance the application of research. If academic structures adequate to the resolution of a problem do not exist, new units must be purpose-built. A new aggregation may at its inception simply represent a best-guess strategic amalgamation. But such reconfigurations may lead to unexpected discoveries through serendipity, or evolve into new interdisciplines. Research universities should promote transdisciplinary collaborations that encourage the conception of knowledge as a common resource for all (Hess & Ostrom 2007).

33.3 Interdisciplinarity by Design in the Contemporary Research University

Reconceptualizing an institution—to accommodate interdisciplinarity, or for any other purpose—can represent a process as deliberate and precise as scientific research or technological invention. Herbert A. Simon affirms the potential for evolution and differentiation in the organization of knowledge enterprises via his distinction between the natural and artificial. "Artificial" simply refers to objects and phenomena—artifacts—that are human-made as opposed to natural. Simon terms knowledge of such products and processes "artificial science" or the "science of design" and observes that the most obvious designers of artifacts are engineers. But he then extends the sphere of the artificial to include our use of symbols—the "artifacts" of written and spoken language. In his expansive usage, everyone is a designer who "devises courses of action aimed at changing existing situations into preferred ones." The natural sciences are concerned with how things are, while the artificial sciences address how things "ought to be in order to *attain goals*, and to *function*." Artificial science—or design science—determines the form of that which we build or construct—pitchforks, farms, or megapolitan agglomerations alike—but also the structures of our institutions (1996, pp. 1–24).

Recent theories of knowledge production suggest the potential for institutional reconfiguration to promote interdisciplinarity. In evolutionary models of organizational adaptation, for example, open systems theory and the biological metaphor of interaction between an organism and its environment serve as the basis for accounts of survival and growth in competitive organizational ecosystems. Open systems theory conceptualizes the interdependence of social structure and external environment and processes of input, throughput, and output. Structure determines the dynamics of operations while increasing complexity is a function of adaptation. In knowledge formations such as universities, information is the principal input, which yields outcomes useful to society. Restructuring is thus key to adaptation and determines the quality of output, that is, the production and dissemination of useful knowledge (Katz & Kahn 1966). The concept of an open system, coined by the pioneering systems theorist Ludwig von Bertalanffy, is central to the objective of a unified transdisciplinary science, as Sytse Strijbos points out. General systems theory, or systems thinking, has informed the interdisciplinary reconfiguration of the academic landscape since the mid-twentieth century. In this context he cites discoveries derived from such fields as cybernetics, information theory, game and decision theory, network theory, systems engineering, and operations research (Strijbos 2010, pp. 453–455).

In some instances the application of existing knowledge is sufficient to advance innovation or produce solutions to problems. In this sense, interdisciplinary collaboration sometimes follows patterns of technological development that are the product of recombinant innovation. W. Brian Arthur explains that this concept refers to the combination or recombination of existing ideas, products, and processes (2009, p. 21). The process of design thus modeled has been characterized by the industrial designers Kees Dorst and Nigel Cross as a sort of coevolution between problem and solution:

> It is widely accepted that creative design is not a matter of first fixing the problem and then searching for a satisfactory solution concept; instead it seems more to be a matter of developing and refining together both the formulation of the problem and ideas for its solution, with constant iteration of analysis, synthesis, and evaluation processes between the two "spaces"—problem and solution. (2001, p. 434)

Theoretical discussions of interdisciplinarity tend to overlook organizational models that may be especially relevant for research universities, which comprise pluralities of intersecting social formations. Knowledge networks and knowledge-centric social formations, including invisible colleges, communities of practice, epistemic communities, and firms construed as knowledge-centric, represent viable models for interdisciplinary collaboration and may suggest institutional workarounds to disciplinary entrenchment. The concept of invisible colleges derives from the early modern period and refers to any collaborative engagement of scholars and scientists focused on similar or related problems. Communities of practice and epistemic communities are knowledge-based social networks. The recognition that firms may be understood as knowledge-centric is implied by their correlation to academic, and especially scientific, research groups (Crow & Dabars 2013, 2015).

Filiopietism and isomorphism both promote the ossification of the American research university. Filiopietism, or the excessive veneration of tradition, encourages adherence to historical models long after their relevance or usefulness has diminished. Isomorphism describes the paradoxical tendency for organizations and institutions operating within a given sector to emulate one another and become increasingly homogeneous but not necessarily more efficient. The outcome of the competition for power and legitimacy that produces dominant organizational models is not differentiation but isomorphic conformity, because the "major factors that organizations must take into account are other organizations" (DiMaggio & Powell 1983, pp. 147, 149). Resistance to novel institutional arrangements is similarly characteristic of the tendencies toward routine, standardization, and inertia that have been identified as hallmarks of bureaucratization (Downs 1967, p. 8). Although bureaucracies deliver essential goods and services and perform functions that facilitate the operations of society, the bureaucratic mindset pejoratively associated with large impersonal public agencies that perform standardized and repetitive tasks is not normally conducive to discovery, creativity, and innovation (Crow & Dabars 2015).

33.4 Some Historical Perspective on the Implementation of Interdisciplinarity

The contemporary context for interdisciplinarity was launched by the first international conference on the topic, convened at the University of Nice in September 1970. Organized by the Centre for Educational Research and Innovation (CERI) in collaboration with the Organization for Economic Cooperation and Development (OECD) and the French Ministry of Higher Education, the Seminar on Interdisciplinarity in Universities introduced the concept to a broader academic culture. Edited by an international committee of scholars, the proceedings were published in an influential report, which Robert Frodeman has termed the "Ur-text of interdisciplinarity" (2014, p. 16). The conference and proceedings consolidated the taxonomy and codified the lexicon of interdisciplinarity—introductory overviews differentiated between disciplinarity, interdisciplinarity, multidisciplinarity, pluridisciplinarity, and transdisciplinarity, for example, and delineated criteria for each category in order to elucidate epistemological distinctions (Apostel et al. 1972, pp. 25–26, 86–89). But these developments by no means marked the onset of the institutional accommodation of interdisciplinarity.

The natural sciences and fields of engineering have historically assumed primacy in spearheading interdisciplinary collaboration, epitomized by the multidisciplinarity of the Manhattan Project. To some extent this predominance may be attributable to large-scale federal government funding of research that spans the spectrum from fundamental to applied (CFIR 2005). But the social sciences and humanities have also played an important role in advancing the interdisciplinary imperative, as evident from a glimpse of highlights of its conceptualization and institutional accommodation, beginning in the 1920s. A passage from the 1934 ten-year retrospective report of the Social Science Research Council (SSRC) expressed

> primary concern with the inter-discipline or interstitial project for the reason that new insights into social phenomena, new problems, new methods leading to advances in the scientific quality of social investigation, cross-fertilization of the social disciplines, were thought more likely to emerge here than from work in the center of established fields where points of view and problems and methodology have become relatively fixed (quoted in Abbott 2001, pp. 131–132).

A contemporaneous exemplar of this impetus is evident in the establishment the following year of university professorships at Harvard University intended for "individuals of distinction . . . working on the frontiers of knowledge, and in such a way as to cross the conventional boundaries of the specialties."

A handful of universities undertook organizational reconfigurations explicitly intended to advance interdisciplinarity in the social sciences and humanities prior to midcentury. Syracuse University, for example, established the Maxwell School of Citizenship and Public Affairs in 1924 to offer graduate professional education in public administration, international relations, and the social sciences. At the undergraduate level, avowedly interdisciplinary programs in the humanities were established at Princeton University in 1936 and Columbia University the following year, where the freshman sequence specified canonical readings beginning with Homer. The celebrated Committee on Social Thought at the University of Chicago, instituted in 1941 by then president Robert M. Hutchins, sought to promote interdisciplinary collaboration between the social sciences and humanities. With themes including literature, philosophy, history, religion, art, politics, and society, the committee differentiated itself from conventional academic departments in its organization "neither in terms of a single intellectual discipline nor around any specific interdisciplinary focus."[2] Other aggregations intended to accommodate and advance interdisciplinarity met with mixed success, and a number of notable programs failed. In the social sciences, for example, the short-lived Department of Social Relations at Harvard University, merging social anthropology, social psychology, and sociology, dissolved with the retirement of its founder, the sociologist Talcott Parsons (Abbott 2001, p. 126).

Representative of more sweeping interdisciplinary reconceptualizations of graduate programs that would emerge following the midcentury is the Program in the History of Consciousness at the University of California, Santa Cruz. Since 1966 the program has sought disciplinary integration through a focus in four broad thematic arenas: race, ethnicity, gender, and sexuality; philosophy and theory; political economy and social movements; and media, aesthetics, and poetics.[3] During the same academic year, the Humanities Center at Johns Hopkins University began offering graduate degrees in both comparative literature and intellectual history. Program literature specifies "free exchange between scholars and students across departmental boundaries."[4] The Program in Modern Thought and Literature (MTL), established in 1969 at Stanford University, derived its methodological approach from the emerging field of cultural studies and sought to position itself "firmly and decisively within a rigorous interdisciplinary framework with fields such as science and technology, media and film studies, legal studies, race and ethnic studies, gender and sexuality studies, medicine, anthropology, and history and philosophy."[5]

In Germany the establishment of Universität Bielefeld in 1969 as an interdisciplinarily structured "reform" university reflects a comprehensive approach that contrasts sharply with the more delimited reorganizations of American institutions. With the Zentrum für interdisziplinäre Forschung (ZiF), or Center for Interdisciplinary Research, intended to constitute the nucleus of the university, the conception was groundbreaking in its ambition to totalize the institutionalization of interdisciplinarity. Modeled on the Institute for Advanced

[2] https://socialthought.uchicago.edu
[3] http://histcon.ucsc.edu
[4] http://humctr.jhu.edu
[5] http://web.stanford.edu/dept/MTL/cgi-bin/modthought/

Study, in Princeton, New Jersey, ZiF has deservedly been termed a nonpareil exemplar of an interdisciplinary think tank. The prescience of this programmatic interdisciplinarity is further attested by its emergence in near contemporaneity with the 1970 conference in Nice and its precedence to the groundswell of interdisciplinary reconfigurations to follow. Representative of more recent efforts is the introduction of a cross-disciplinary research strategy by University College London in 2011 that sought to produce a "culture of wisdom" organized around a set of broad "grand challenge" themes: global health, sustainable cities, intercultural interaction, and human well-being. Such alternative principles for organizing knowledge production inevitably assume interdisciplinary dimensions.

33.5 A Case Study in the Accommodation and Advancement of Interdisciplinarity

The advancement of interdisciplinary knowledge production has been one of eight explicit "design aspirations" associated with the comprehensive reconceptualization of Arizona State University (ASU), the youngest major research institution in the United States and, with 91,357 undergraduate, graduate, and professional students enrolled in fall 2015, the largest university governed by a single administration. The reconceptualization was conceived with the objective of establishing a foundational prototype for a new alternative model for a subset of public research universities. The New American University model developed by Michael M. Crow during his presidency of the university combines accessibility to an academic platform underpinned by discovery and a pedagogical foundation of knowledge production, inclusiveness to a broad demographic representative of the socioeconomic diversity of the region and nation, and maximization of societal impact. The reconfiguration of academic departments and disciplinary fields undertaken to accommodate interdisciplinarity must be appreciated within this broader context (Crow & Dabars 2015, pp. 7–8, 62).

As one aspect of the reconceptualization of the university, the design process sought to create a distinctive institutional profile through the reconfiguration of existing academic units and a deliberate and complementary clustering of programs arrayed across four differentiated campuses. The objective was to produce a federation of unique transdisciplinary departments, research centers, institutes, schools, and colleges—henceforth generally referred to as "colleges and schools," with colleges representing a particular amalgamation of schools. These new academic entities ("new schools") were established to advance teaching and engender research, both fundamental and applied, of sufficient interdisciplinary breadth to address large-scale challenges. Nearly all research centers and institutes are construed along interdisciplinary lines, encouraging necessary specialization but not the fragmentation of knowledge.

An initial assessment of the institutional disciplinary landscape sought to articulate the identities of disciplines and interdisciplinary fields and chart their interrelationships and anticipated trajectories. Alignments between fundamental and irreducible disciplines and interdisciplinary configurations were calibrated, inasmuch as these relations may be synergistic, symbiotic, or even antagonistic. Following reconceptualization, some core disciplines remain departmentally based, while others have been unbundled and construed across explicitly interdisciplinary academic units. The accommodation of interdisciplinarity generally aligned with the intent to facilitate teaching and research in a given field or, more narrowly, to address a specific research challenge. The identification of an objective, whether strategic, tactical, or methodological, in some cases motivated the establishment of a particular academic unit.

This reconfiguration of institutional frameworks might easily have become fraught with interminable political contestations. Each stage, however, was negotiated with minimal strife largely through appeals to common sense as well as exhaustive trial and error construed according to a "design-build" metaphor. Design-build is a paradigm borrowed from the architectural profession and construction industry, which refers to the integration of conception and execution by a single team. The sequence of interactions might thus be likened to a series of charettes, which the *Oxford English Dictionary* defines as a "period of intense (group) work, typically undertaken in order to meet a deadline. Also: a collaborative workshop focusing on a particular problem or project." In some cases the relative autonomy of design teams arguably assumed the tenor of a "skunkworks," an industry term that in broad usage specifies an informal and autonomous group often working in isolation. While sometimes tumultuous and argumentative, retrenchment to the proverbial drawing board permitted radical differentiation. A "blank slate" standpoint encourages productive thought experiments and inevitably trumps futile attempts to anticipate every possible exigency. The alternative of incremental change is generally insufficient to accomplish transformative reconceptualization. The architectonic metaphors enlisted in this context suggest the imperative for structural change as well as continuous adaptation and recalibration through repeated course corrections (Crow & Dabars 2015, p. 247).

Even prior to the operationalization of the design process, the impetus to reorganize and recombine discipline-based academic departments had already gained momentum, epitomized by an ambitious reorganization of the life sciences faculties. In July 2003, the biology, microbiology, and plant biology departments and the program in molecular and cellular biology merged to form the new ASU School of Life Sciences (SOLS). Although administrative efficiency was cited as an objective, the motivation described in the 2010 strategic plan was largely to advance interdisciplinarity: "to facilitate collaboration across the range of disciplines covered by the school; . . . and to exploit the fact that the key research challenges in the life sciences lie at the interface of sub-disciplines, often involving integration of knowledge from different levels of biological organization and across different kinds of organisms." Conceived "without internal disciplinary barriers, allowing it to plan strategically at the seams of intersecting disciplines," the school is currently organized into seven faculty groups: biomedicine and biotechnology; cellular and molecular biosciences; genomics, evolution, and bioinformatics; ecology, evolution, and environmental science; human dimensions of biology; organismal, integrative, and systems biology; and basic medical sciences. Within this framework more than one hundred life scientists, engineers, philosophers, social scientists, and ethicists self-organize around the socially and environmentally relevant questions of the day.

Among the new transdisciplinary schools conceptualized and operationalized during the past decade are the School of Earth and Space Exploration (SESE); School of Human Evolution and Social Change (SHESC); School of Politics and Global Studies; School of Social Transformation; and School of Historical, Philosophical, and Religious Studies (SHPRS). The School of Earth and Space Exploration epitomizes efforts to institutionalize interdisciplinarity. Established through an amalgamation of the former Department of Geological Sciences and the astronomy, astrophysics, and cosmology faculties of the former Department of Physics and Astronomy—thereafter the Department of Physics—SESE includes theoretical physicists, systems biologists, biogeochemists, and engineers who advance the development and deployment of critical scientific instrumentation. Transdisciplinary fluidity facilitates collaboration between scientists and engineers, engaging researchers from other schools and institutes. As described in a 2010 academic program review, subfields within astrophysics and cosmology, for example, include computational astrophysics; physics of the early universe; and the formation of galaxies, stars, and planetary systems. The broad theme of exploration represents a transdisciplinary conceptualization of the quest to discover the origins of the universe and expand our understanding of space, matter, and time.

Existing academic units have similarly been reconceptualized along interdisciplinary lines. The Ira A. Fulton Schools of Engineering, for example, have evolved from a conventional college of engineering and applied sciences to comprise five distinct research-intensive transdisciplinary schools, including the School of Biological and Health Systems Engineering; School of Computing, Informatics, and Decision Systems Engineering; School of Sustainable Engineering and the Built Environment; and the Polytechnic School, which focuses on use-inspired translational research, and offers students interested in direct entry into the workforce an experiential learning environment. The Herberger Institute for Design and the Arts, to consider but one further example, comprises the School of Art; School of Film, Dance, and Theater; Design School; School of Music; and in collaboration with the Fulton Schools of Engineering, School of Arts, Media, and Engineering, which conducts research on experiential media that integrate computation and digital media with embodied human experience.

Large-scale transdisciplinary research initiatives complement new schools. The Julie Ann Wrigley Global Institute of Sustainability (GIOS), which incorporates the School of Sustainability, focuses on environmental, economic, and social sustainability. The Biodesign Institute, a premier multidisciplinary research center advancing biologically inspired design, addresses global challenges in healthcare, sustainability, and national security. Working in the broad domains of biological, nanoscale, cognitive, and sustainable systems, the more than a dozen transdisciplinary research centers that constitute the institute advance understanding in human health and the environment through research in such areas as personalized diagnostics and treatment, infectious diseases and pandemics, and renewable sources of energy.

Allied transdisciplinary configurations include the Complex Adaptive Systems Initiative (CASI), a collaborative effort to address global challenges in health, sustainability, and national security; Security and Defense Systems Initiative, which addresses national and global security and defense challenges through an integrative systems approach; Flexible Display Center, a cooperative agreement with the US Army to advance the emerging flexible electronics industry; and LightWorks, an endeavor in renewable energy fields, including artificial photosynthesis, biofuels, and next-generation photovoltaics.

Transdisciplinary initiatives in the humanities and social sciences include the Institute for Humanities Research; Center for the Study of Religion and Conflict, which promotes research on the dynamics of religion in contemporary society with the objective of seeking solutions and informing policy; and School for the Future of Innovation in Society, which originated in the Consortium for Science, Policy, and Outcomes (CSPO). The consortium is dedicated to interdisciplinary examination of the societal and cultural context within which science is conducted and seeks to enhance the contributions of science and technology to an improved quality of life, with particular attention to distributional impacts—questions of who is likely to benefit from public investments in knowledge production and innovation. Science policy crucially influences the types of benefits that science confers, the distribution of benefits, and the emergence of new problems. That it remains a marginal part of public discourse and policy action is the principal motivation for the consortium.

The momentum of interdisciplinary knowledge production at ASU may in part be attested by the growth in the number of active sponsored projects involving investigators from different academic departments, which rose by 75% between FY 2003 and FY 2014, outpacing projects involving researchers in single departments, which increased by only 8%. The total value of active sponsored projects from single units during this time frame increased 61.7%, while the value of projects involving more than one unit increased 259%. Even so, for some scholars and scientists, allegiance to the invisible colleges of disciplinary affiliation trumps unreserved engagement with new interdisciplinary configurations. And while the potential of interdisciplinary approaches appears to be validated by its broad advocacy within the academic community, the corollary challenge remains for institutions to produce students who are adaptive master-learners empowered to integrate a broad array of interrelated disciplines and negotiate the changing workforce demands of the knowledge economy.

Individually, none of the design strategies undertaken in this context appears especially remarkable. What is distinctive is the symbiotic dynamism of their interrelated and interdependent deployment. All such reconceptualizations are necessarily sui generis, because no aspect of institutional design should ever be generic. The purposes of this chapter therefore do not include the prescription of a codified set of design strategies applicable in all such efforts. Rather, through an assessment of one particular reconceptualization, we hope to call attention to the focus and deliberation requisite to the implementation of interdisciplinarity.

33.6 Toward Mutual Intelligibility in the Academy

The contemporary research university remains a Tower of Babel where, as C. P. Snow put it more than a half-century ago, "persons educated with the greatest intensity we know can no longer communicate with each other on the plane of their major intellectual concern" (1963, p. 60). The maintenance of strict disciplinary boundaries undermines our impetus to initiate a conversation with those outside our own sphere of disciplinary expertise. Yet biologists alone cannot solve the loss of biodiversity nor chemists in isolation negotiate the transition to renewable energy. Neither biologists nor chemists have developed a lingua franca to facilitate communication with philosophers or engineers. Because each academic discipline exercises its own vernacular, the impetus is lacking to cultivate "interlanguages" intelligible to other disciplines—the pidgins or creoles that constitute the mutually comprehensible means of communication through which different subcultures negotiate trading zones (Galison 1997, 48). Stefan Collini aptly frames this imperative as the "intellectual equivalent of bilingualism," which he defines as a "capacity not only to exercise the language of our respective specialisms, but also to attend to, learn from, and eventually contribute to, wider cultural conversations" (1998, p. lvii). If we are to advance collaborative innovation, the debate must engage a broad community of disciplines as well as the wisdom and expertise developed in commerce, industry, and government.

Even before the emergence of organized science, our intellectual progenitors intuitively understood the need to think at scale and across disciplines. Four centuries of scientific focus on the ever smaller and more fundamental secrets of nature have seemingly impaired our ability to frame inquiry commensurate to the challenges that confront us. Although disciplinary specialization has been key to scientific success, such specialization threatens to erode holistic understanding. It has also diminished our ability to construe teaching and research between and among the disciplines. Long before the advent of interdisciplinarity as a normative concept, research and scholarship spanning multiple domains had characterized the quest for useful knowledge that from the outset of the American republic had been the hallmark of its academic culture. But the academy today and science in particular uses disciplinary organization to recognize and focus on questions that *can* be answered while there is absolutely no a priori reason to assume that what we *can* know is what we most *need* to know (Crow 2007). Our collective survival as a species may be contingent on our capacity to adapt and innovate, which assumes the continued evolution of knowledge enterprises optimally designed to foster mutual intelligibility among academic disciplines and interdisciplinary fields.

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CHAPTER 34

PEER REVIEW, INTERDISCIPLINARITY, AND SERENDIPITY

J. BRITT HOLBROOK

DESPITE seemingly radical changes to scholarly communication (Mandavilli 2011), peer review remains the tool of choice for decisions about publication, promotion and tenure, and grant proposals, and in the evaluation of research groups, departments, programs, and universities. When then National Science Foundation (NSF) director Subra Suresh convened the Global Research Council—made up of the heads of major research funding agencies around the world—in 2012, it was no accident that the topic of the first meeting was peer review (Holbrook 2015a). That some bit of research, some academic, some program, or some university has passed through the process of peer review is *the* mark of academic excellence.

Academic excellence, however, is often inversely proportional to societal relevance. Indeed, the greater the identification of academic excellence with disciplinary standards, the greater the risk of irrelevance to anyone outside the discipline becomes. Interdisciplinary research is increasingly encouraged as a way of making academic research more societally relevant. Academic research is also called on to help societal decision makers craft evidence-informed policies, and peer review remains the preferred tool for ensuring the integrity and reliability of the research used by decision makers.

Since disciplines largely define who counts as a peer, these trends toward interdisciplinarity and transdisciplinarity for research strain the process of peer review. The key issue for those who rely on peer review is whether a tool that has been used mainly to determine academic excellence can be adapted to judge societal relevance without undermining the foundations of knowledge production (Sarewitz 2000; Biagioli 2002).

34.1 Background: The View from inside Academe

Peer review is a process by which a group of individuals renders judgment on the work of others in order to determine whether that work is meritorious enough to warrant

Holbrook, J. B., *Peer Review, Interdisciplinarity, and Serendipity.* In: *The Oxford Handbook of Interdisciplinarity, Second Edition.* Edited by Robert Frodeman, Julie Thompson Klein, and Roberto C. S. Pacheco: Oxford University Press (2017). © Oxford University Press. DOI 10.1093/oxfordhb/9780198733522.013.39

consideration (e.g., for publication or tenure) or support (e.g., in the form of a grant or fellowship). Typically, the individuals asked to render such judgments are selected from a pool of reviewers who are considered to be "peers" of whoever has produced the work to be judged. What constitutes a peer is more complicated than one might think; but given the uses to which the process of peer review has been commonly put, a peer has traditionally been characterized in terms of shared disciplinary expertise.

The a priori justification for using peer review as an assessment tool is relatively straightforward: no one is in a better position to assess the merit of work in a particular area than experts in that particular area. Thus, in order to judge whether work in area P is meritorious, it makes sense to ask individuals renowned for their expertise in area P rather than people who know comparatively little or nothing about P. Although individual nonconformists exist, along with several quasi-disciplines, which may or may not be evolving toward disciplinary status, areas of academic expertise are most often carved out by and within academic disciplines. Indeed, the connection between academic excellence and disciplinary expertise is so common that interdisciplinarity among academics is often perceived as amateurism (cf. Frodeman & Mitcham 2007; Baker, this volume).

Despite the fact that the standards of one academic discipline may be incommensurable with those of other disciplines (Holbrook 2013a), there is near universal agreement across academe that peer review is essential for determining what counts as academic excellence. Indeed, publications that are not peer-reviewed typically do not count—either at all or as much as—peer-reviewed articles when it comes to tenure and promotion standards for higher education faculty; and the majority of grants from public funding agencies are allocated only after and on the basis of some form of peer review. For this reason, the process of peer review is usually characterized in terms of "quality control" or as having a "gatekeeper" function, and it is no exaggeration to say that peer review is the sine qua non of academic excellence.

The most common uses of peer review are in academic publishing (e.g., to determine whether a paper submitted for publication in an academic journal is worthy of being published in that journal) and in the review of proposals for grants (e.g., to determine whether the proposed activities deserve to receive funding). Both prepublication peer review and grant proposal peer review are *prospective* uses of peer review, which ostensibly puts a great deal of pressure on reviewers to predict the future: Will this paper (or this proposed research) ultimately be well received by the field? In most, though not all, cases of prospective peer review, the identity of the reviewers is withheld from the reviewee (a process known as blind peer review); and in many cases of prospective peer review, the identity of the reviewee is also withheld from the reviewers (a process known as double-blind peer review).

The process of peer review is also increasingly employed to conduct *retrospective* analyses of particular people, practices, or institutions. For instance, peer review may be employed within an academic department to rank the performance of individual members of the department relative to other members of the department. Often, "external" reviewers are brought in to assess the strengths and weaknesses of the business practices of a particular company or to identify strengths and weaknesses on an institutional level, judging a university, a particular program within a research funding agency, or the agency as a whole. Some have even suggested that retrospective evaluation in the form of postpublication peer review should replace the process of prepublication peer review (Swartz 2013). Often, cases of retrospective peer review make fewer, if any, attempts to hide the identity of reviewers and reviewees from one another through blinding. Because of dissimilarities with the typical peer review process, which relies heavily on the use of disciplinary peers as reviewers, many are reluctant to call retrospective institutional review peer review at all, preferring instead to refer to this practice as *expert* review. There also exist other "extensions" of the peer review process, that is, atypical uses of peer review, such as the use of peer review in relation to regulatory decision-making (Jasanoff 1990).

Typical criticisms of the process of peer review include the worry that it may be potentially biased against people for reasons unrelated to the merit of their work (Wennerås & Wold 1997). Blinding reviewers and reviewees to the identity of the other is an attempt to allay this criticism. Some critics suggest that peer review is an inefficient and unwieldy tool for evaluating large volumes of research. In response, some funding agencies have taken the step of limiting grant proposal submissions, for example, by shortening the allowable length of proposals, previewing letters of intent and accepting only invited full proposals, limiting the number of proposals particular institutions may submit for particular calls, or limiting the number of submissions a particular researcher may make of the same proposal.

Another common criticism of peer review is that it is inherently conservative, tending to favor work conducted along traditional lines (in the sciences this concern is often expressed in terms of bias toward existing paradigms and against novel or revolutionary ways of thinking). To counter conservatism, reviewers are sometimes instructed to value paradigm-shifting or "transformative" ideas (Frodeman & Holbrook 2012). Another counter-conservative tactic that funding agencies use is to put out calls for interdisciplinary research proposals. Reviewing interdisciplinary proposals, however, presents special difficulties (Lamont 2009; Holbrook 2013a, 2013b; Huutoniemi & Rafols, this volume).

One of the most notorious criticisms of peer review is that it is ineffective at determining quality and/or detecting errors (e.g., the so-called Sokal Affair or the widely publicized failure of reviewers to detect the falsification of data by Hwang Woo-Suk in publications on stem cell research in 2004 and 2005 in the journal *Science*). The typical response to this criticism is to deflect it with humor: Winston Churchill's quip about the value of democracy is paraphrased, and peer review is admitted to be the worst form of research evaluation, except for all the others. In this way, advocates of peer review effectively divert the conversation back to considerations that do not threaten the very existence of peer review: how to improve its efficiency, reliability, responsiveness, and fairness (and hence its overall effectiveness). Biagioli (2002) stands out in the literature on peer review for his willingness to take peer review seriously as a condition for the possibility of knowledge production.

34.2 A History of Peer Review

It is a commonly held belief that the process of peer review is venerable because it is ancient, as opposed to merely respectable because it is institutionally well entrenched. Searching for "the first documented description of a peer review process," the *2007–2008 Peer Review Self Study* published by the National Institutes of Health (NIH) cites two articles published in a 1997 issue of the *Annals of Saudi Medicine* that note a peer review process described "more than a thousand years ago in the book *Ethics of the Physician*, authored by Syrian physician Ishaq bin Ali al-Rahwi (CE 854–931)" (NIH 2008, p. 8). *Ethics of the Physician* "outlines a process whereby a local medical council reviewed and analyzed a physician's notes on patient care, to assess adherence to required standards of medical care" (NIH 2008, p. 8). This description seems most reminiscent of medical peer review, which is a quasi-judicial, retrospective fact-finding procedure to determine whether (as with a grand jury) a hearing is necessary. Of course, according to a sufficiently broad definition of peer review, one might also cite the Athenian judicial system: Socrates's trial (as documented in Plato's *Apology*) might be seen as a kind of peer review process, and his practice of confronting and examining his "peers" in the *agora* (as documented throughout Plato's early dialogues) could also count.

Most histories of peer review trace the origin of prepublication peer review to the Royal Society of London and its journal *Philosophical Transactions*, founded by the Royal Society's first Joint Secretary, Henry Oldenburg, in 1665. Although no one questions whether Oldenburg deserves credit as the founder of the world's longest-running scientific journal, whether his practice of passing manuscripts around to members of the Royal Society prior to publishing them in the *Philosophical Transactions* actually constitutes the "real" origin of the prepublication peer review process is the matter of some debate (Kronick 1990, 1994; Spier 2002; Royal Society 2009). Regardless of its "real" origin, Spier (2002) notes that both the practice of prepublication peer review and the time of its adoption vary from journal to journal, and that the practice did not become widespread until after the Xerox photocopier became commercially available in 1959.

A similar story also fits the development of grant proposal peer review processes. One finds attempts to pinpoint the "real" origin of grant proposal peer review. For instance, Scarpa (2009) dates the very first (ad hoc) peer review of grant proposals to 1879; and Germany's *Notgemeinschaft der Deutschen Wissenschaft*, predecessor of the *Deutsche Forschungsgemeinschaft* (DFG), had a review system during the 1920s, which was later adopted by the DFG in 1951. However, the robust institutionalization of grant proposal peer review began around the middle of the twentieth century with the passage of the Public Health Service Act of 1944 in the United States, which authorized the NIH to make grants, an extension of the power that in 1938 had been limited to the National Cancer Institute. The NIH quickly established a Division of Research Grants to oversee NIH's peer review process. In the late 1940s, the US Office of Naval Research (ONR) also began making grants, although no formal peer review process was required. Instead, grants officers occasionally asked experts to review proposals in order to help them make their decisions. In 1950, the US National Science Foundation (NSF) was founded, and the NSF adopted a process of grant allocation that not only copied the strong program manager model from the ONR but also incorporated an official peer review process, like NIH. The NSF's peer review process remains to this day less standardized than that of NIH, but more standardized than that of the ONR.

Two salient features regarding peer review stand out from the foregoing historical account: (1) Peer review is not as ancient a practice as many assume—it was not widely practiced in either publication or grantmaking until after the middle of the twentieth century; and (2) in both prepublication peer review and grant proposal peer review, practices vary widely. Although we scholars have largely forgotten the novelty of peer review—it has become, for us, *the* mark of quality—the immense variety of peer review processes raises a fundamental question: Who counts as a peer? Why do we consider an editor or a funding agency official, both of whom are typically experts in the field, and both of whom certainly review work before it is published or awarded a grant, to be anything other than peers?

Yet, despite many criticisms of the process and the inherent ambiguity surrounding who counts as a peer, members of the academic community are almost unanimous in their support of peer review as a decision-making tool, both for publication and for grantmaking purposes (Boden Report 2006). This near unanimity of support cannot stem from the fact that peer review is the way things have always been decided in academe, for that simply is not the case. Nor can academics' support of peer review stem from a univocal understanding of who counts as a peer. Instead, the real value underlying peer review—at least for academics—is academic freedom.

34.3 Autonomy and Expertise: The Disciplining of Peer Review

In part, the institutionalization of peer review is motivated by the growth of academic disciplines, both in terms of the *fact* of their growth (i.e., the fact that academic disciplines became, in the nineteenth century, the new model for how research was to be conducted within the German and American research universities) and in terms of the *need* for growing particular disciplines (a need generated by the invention of this new model of the university). Along with the disciplinary division of labor advocated by Kant at the end of the eighteenth century, this new model for the university incorporated a strong demand for autonomy. Wilhelm von Humboldt's "On the Spirit and Organizational Framework of Intellectual Institutions in Berlin" proclaims:

> The state must always remain conscious of the fact that it never has and in principle never can, by its own action, bring about the fruitfulness of intellectual activity. It must indeed be aware that it can only have a prejudicial influence if it intervenes. The state must understand that intellectual work will go on infinitely better if it does not intrude. (1970, p. 244)

According to Humboldt's vision, the state's only role should be to facilitate the conditions necessary for the greatest production of knowledge (for the sake of knowledge, rather than for the sake of the state)—to serve an instituting, but not an institutional role vis-à-vis the university. Humboldt's justification for the state's playing this facilitating role is that the state will ultimately benefit from supporting the unfettered pursuit of knowledge in the university.

Incorporating both a division of labor and a strong sense of autonomy, the new universities produced both more knowledge and more specialized knowledge, simultaneously cultivating depth (as defined by particular disciplines) as the mark of excellent research and reinforcing the divisions between disciplines. Just as the desire to form the "new science" led to the formation of the Royal Society of London and to Oldenburg's establishment of the *Philosophical Transactions*, the desire to form new disciplines led to the establishment of new, disciplinary journals. As disciplines grew, they produced both more and more-specialized knowledge, which spawned both more and more-specialized journals. Competition for resources between universities, between different disciplines within universities, and between faculty members within departments eventually led to the "publish or perish" mentality, as well as to increasingly sophisticated ways of judging whether one journal were better than another, ranging from the relative prestige of the editors or the academic home of the journal to circulation and impact factors.

The most widely used—and crudest—measure of the worth of any particular journal, however, is whether that journal is peer reviewed. This is true despite the fact that the peer review process across journals varies widely. The case is much the same for the outputs of research, namely publications. Indeed, that a particular line of research does not appear in the peer-reviewed literature is taken as prima facie evidence of its lack of quality (e.g., the case of intelligent design theory); and publication in peer-reviewed journals is the coin of the realm of many disciplines, largely determining the outcome of many tenure and promotion cases. The close link between peer review and disciplines also presents problems for those who are seeking to explore interdisciplinarity in their own scholarship (Dooling et al., this volume).

There is a remarkable unity of themes between Kant's call for the division of labor in research, Humboldt's plea for facilitated autonomy for the university, and the canonical document of post–World War II science-funding policy in the United States, Vannevar Bush's *Science: The Endless Frontier* (1945). Echoing both Kant and Humboldt, Bush argues for state support of autonomously pursued basic research, that is, research pursued for its own sake, without concern for the practical ends that are the proper province of applied research. According to the Bush conception, applied research, which yields technological, medical, and military advancements, fundamentally depends on basic research. Just as Humboldt had argued at the turn of the nineteenth century, Bush suggests that although the particular uses of basic research and the eventual benefits that will accrue are difficult to predict, societal benefits cannot occur unless scientists are allowed to pursue science without interference from the state—a notion that was later labeled as the linear model (or sometimes, linear-reservoir model) of science.

Because Bush was asking for large outlays of public funds, and on a continuing basis, in support of the unfettered pursuit of basic scientific research, some form of accountability needed to be built into the system. Indeed, there was a great deal of debate between the strong-autonomy advocates in the Bush camp and the more pragmatic adherents of the views expressed in the Steelman Report (1947), which advocated more limited scientific autonomy in the name of a stronger connection to public benefit. Bush's advocacy of a strong form of autonomy ultimately won the day when the NSF was created in 1950. Arguably, however, one reason the NSF abandoned the ONR model for grants decision-making, in which a program officer can make funding decisions without subjecting proposals to peer review at all, was the controversy over the demands for the autonomy of research and the demands for more closely linking research to societal benefits. Peer review of grant proposals is meant to guarantee that scientists have a large degree of autonomy when it comes to making decisions about which particular research proposals ought to receive funding, while simultaneously demonstrating their accountability for making wise use of public funds.

The success of the process of peer review in guaranteeing autonomy for the academic pursuit of knowledge, along with concomitant financial support in the form of public funding for research, are key drivers of academe's love affair with peer review. But the fact that society allows peer review to serve this dual function—providing autonomy and asking only self-regulation as accountability—perhaps needs some explanation, given society's ambivalence, or what Jasanoff (1990) terms "oscillation between deference and skepticism," toward experts (p. 9).

Even as we profess our distrust of experts, we evidence faith in expertise. We routinely follow the advice of doctors when it comes to our health and of mechanics when it comes to our cars. Indeed, we ignore the advice of experts at our own risk. It is also the case that what constitutes an autonomous academic discipline, at least in part, is there being something it is, some field of knowledge, which is its special task to pursue. Academic journals mark out this disciplinary territory, and prepublication peer review ensures that this territory is marked well (i.e., according to the standards of the discipline). Academics are experts, and even within academe, perhaps especially so in the context of peer review, scholars from different disciplines display a remarkable deference to the expertise of scholars from other disciplines (Lamont 2009). The experts trust the other experts; is it really any wonder, then, that nonacademics should have some faith in peer review?

Academics and nonacademics tend to share the presumption that knowledge is something that comes along with specialization and the depth that such specialization brings—what Frodeman (2004) critiques as an epistemology of external relations and opposes to a kind of epistemological holism. An epistemology of external relations—or epistemological reductionism—tends to support analysis: Knowledge is gained by examining parts of reality, which can later be pieced together (somehow—reductionism tends not to spend too much time on how this might happen). Epistemological holism, however, holds that knowledge of the whole is always greater than the sum of knowledge of its parts. Epistemological reductionism tends to support the idea of expertise, whereas an epistemological holism tends to undermine the idea of expertise (Sarewitz 2010). Epistemological reductionists tend also to think that more knowledge is always a good thing; Humboldt (1970) insists that the pursuit of knowledge is an infinite task. Epistemological holists tend to believe in limits to knowledge (Frodeman 2013). Discipline-based peer review is essentially founded on an epistemology of external relations, and part of the explanation for our overall acceptance of the process of peer review is that we tend—whether we realize it or not—to view knowledge in (reductionist) terms of external relations. Because we tend to view knowledge in reductionist terms, the notion of expertise seems intuitively obvious to us.

Another factor supporting our faith in peer review is that we tend to ignore the fact that peer review has a history—and it has a far shorter one than many presume. Adhering to the process of peer review is not simply a disinterested matter of scholarly housekeeping on the part of academe or objectivity on the part of grantmaking institutions or societal decision makers. Rather, the process of peer review has its roots in the institutional disciplinization of knowledge production, a process that has always been as political as it has been epistemological. Within the university setting, disciplines deserve at least as much identification with power as knowledge does: in its role as the valuator of academic and scholarly work, the process of peer review acts to wall off disciplines from each other, guaranteeing the existence of disciplinary islands where petty princes (or tyrants) rule. In its role as guardian of autonomy from societal influence, peer review also walls off academe from the rest of society, guaranteeing freedom at the price of isolation. Discipline-based peer review *is* the gatekeeper—not only of the little disciplinary hearths within academe, but also of the Ivory Tower itself.

34.4 Interdisciplinary, and Transdisciplinary Pressures on Peer Review

Academic excellence is one thing; relevance to anything in the world outside academe, however, is usually something altogether different. Often, academic rigor—and relevance within disciplinary scholarship—is achieved only at the price of irrelevance to anyone outside that academic discipline or subdiscipline. Put differently, academe has disciplines and the "real" world outside of academe has problems—none of which are "merely academic."

Interdisciplinarity is often touted as the way to free academics of their disciplinary blinders so that they can begin to develop real solutions to real problems. Yet interdisciplinarity creates all sorts of problems within academe, not the least of which are problems with peer review. As Huutoniemi and Rafols (this volume) point out, evaluating interdisciplinary research is exceedingly difficult given the lack of agreed on standards that disciplines provide. Graybill (this volume) also points to problems for early career academics trained as interdisciplinarians, who are caught between publishing for the discipline that houses them or for a "new academy" that is yet to materialize. Promotion and tenure decisions invariably turn on a record of publication in high-quality journals, which are invariably organized (and peer reviewed) along disciplinary lines. Both of these chapters raise the fundamental question for academic interdisciplinarity: Who counts—or who *should* count—as a peer?

Although this question does arise for the "old academy"—for instance, it is typical to question whether more established investigators within a field are truly peers of early career academics or vice versa—the typical answer is that *disciplines define peers*. It is this answer that brings into relief the difficulty of evaluating interdisciplinary or transdisciplinary research (whether publications or grant proposals). The previous iteration of this chapter (Holbrook 2010) considered the case of the NSF's Broader Impacts Merit Review Criterion—which asks proposers to address and reviewers to assess the potential impacts on and benefits to society of the proposed research—as an example of the transdisciplinary pressure being placed on peer review. However, the case of the NSF, unique as it is, is not unlike changes to peer review processes at other public science funding agencies around the world, many of which have incorporated similar societal impacts criteria into the process of peer review (Holbrook 2013b). Rather than merely updating this chapter with accounts of these other agencies, I turn now to a consideration of how such interdisciplinary and transdisciplinary pressures on peer review might be addressed.

34.4.1 Incremental Modifications to Peer Review

Peer review processes can certainly be modified incrementally to account for interdisciplinary and transdisciplinary goals. Consider the following argument. Disciplinary expertise is required to assess disciplinary excellence. Hence, reviewers charged only with assessing the disciplinary merit of a grant proposal (or article submission) need only be selected from the particular discipline under consideration. A mix of disciplinary expertise(s) is required to assess academic excellence beyond a single discipline. Hence, reviewers charged with assessing the merit of multidisciplinary or interdisciplinary proposals ought ideally to be selected from all the disciplines included in the proposals. Although review of such multidisciplinary and interdisciplinary proposals is more complicated than monodisciplinary review, it nevertheless takes place within academe, where each reviewer is ideally accorded a kind of authority over her own disciplinary domain (cf. Lamont 2009).

This argument can also be extended to address transdisciplinarity. When societal impacts criteria go beyond the realm of academe to address societal relevance, if proposers are to make their research societally relevant and reviewers are to judge societal relevance, then who counts as a peer should be extended to include nonacademic members of society at large. In other words, if we introduce transdisciplinary criteria into the process of peer review, then we should expand the definition of who counts as a peer beyond the boundaries of the disciplines. Such an approach preserves, as far as possible, the disciplines as the foundation of peer review. It proposes incremental changes, gradually expanding the idea of disciplinary expertise to experts from other disciplines, and eventually to "experts" outside of academe (these people are sometimes called "stakeholders"). Yet, such an incremental approach—one rooted firmly in an epistemology of external relations—both threatens to undermine peer review and ignores the fact that peer review has never been only a disciplinary activity. The incrementalist approach treats disciplines as primary. In doing so, it holds on to the belief that disciplines define peers. At the same time, however, it proposes to expand who counts as a peer for purposes of interdisciplinarity or transdisciplinarity. But such an expansion of who counts as a peer increases the tension between disciplines, as well as the tension between academe and society. It risks institutionalizing a class system, in which the "real" peers are disciplinary, the middle class are peers from other disciplines, and the peasants from outside academe are granted occasional privileges. Alternatively, the supposed "real" peers who mix with the hoi polloi risk having their claims to expertise questioned. After all, if nonacademic stakeholders count as peers, then their opinions count just as much as those of the "real" experts.

34.4.2 Replacing Peer Review with Metrics

The twenty-first century has arrived with new technological capabilities that promise to resolve the interdisciplinary and transdisciplinary problems faced by peer review not with an incremental modification to the process, but with a revolution! If *The Graduate* taught us the one word, just one word, of the twentieth century was "plastics", the one word for the twenty-first century—at least for twenty-first-century research evaluation—is "metrics." There is a great future in metrics. But let us think about it.

Although Eugene Garfield's *Science Citation Index* and the scientometric approaches to research evaluation it facilitates were decidedly twentieth-century inventions, the twenty-first century has seen an explosion of new uses for these and other similar tools. The *h*-index—in which a single number is assigned to an individual author in order to capture both the quantity and quality of the author's contributions to knowledge—is perhaps the most well-known example (Hirsch 2005). The *h*-index not only led to a proliferation of new quantitative indicators of scholarly impact, but also promised to democratize the use of such indicators. No longer did one need to be an expert in scientometrics in order to determine the scholarly impact of a particular author or publication. Anyone with access to a citation database could calculate a scholar's *h*-index. In 2012, Google Scholar, which calculates individual scholars' *h*-indexes for us, along with other metrics, began allowing individual researchers to create their own profiles. These profiles are also accessible to the public, allowing anyone with access to the Internet to find the quantified worth of academics from around the world.

The new metrics are not limited to disciplinary scholarly impact, either. October 2010 saw the publication of *Altmetrics: A Manifesto*, which promised to measure impact in ways that moved beyond old-fashioned citation counts (Priem et al. 2010). Incorporating traces left on the Web, altmetrics capture all sorts of conversations (e.g., on Twitter), mentions (e.g., in blogs), and nontraditional citations (e.g., in Wikipedia). Today, altmetrics take many forms, from the numbers-informed narrative of Impactstory.org to the single article-level number generated by Altmetric.com. Indeed, altmetrics today are so diverse that the National Information Standards Organization (NISO) has organized an attempt to standardize them (NISO 2016). Even without established standards for what counts as an altmetric, researchers are exploring whether altmetrics can account for just the sort of broader impacts on society traditional scholarly impact metrics miss (Holbrook et al. 2013, Philosophy Impact 2016).

Metrics for scholarly and broader impacts present a different threat to peer review than that posed by incremental changes to the peer review process. Whereas the latter may erode peer review over time, metrics radically democratize expertize by allowing anyone with access to the Internet to put numbers on scholars and their scholarly products, numbers that allow anyone to compare one (publication, scholar, or group of scholars) to another. Expert peers are expendable in a world in which anyone can judge academic worth at the press of a button.

Interestingly, scientometricians have recognized that metrics can be used—or, according to their characterization, misused—in this way. The "Leiden Manifesto" (Hicks et al. 2015) is an attempt by scientometricians to lay out a set of principles—almost a code of ethics—to govern the use of scientometric tools and methods. Like the NISO effort to standardize altmetrics, however, such an approach risks lending the *imprimatur* of a single academic discipline to democratized research evaluation. As long as it is performed according to the standards of the expert scientometricians or altmetricians, after all, who can argue with the results?

34.5 Serendipity: Sagacity Regarding Opportunity

Both the incremental and revolutionary approaches to responding to the interdisciplinary and transdisciplinary pressures on peer review undermine the larger transdisciplinary purpose of peer review—to guarantee the autonomy of academe from society. However, an alternative approach to peer review, which goes beyond the incrementalist approach and incorporates some of the new metrics, is also possible. According to this alternative view, the very idea of academic autonomy as simply freedom *from* society is ill-conceived. Instead, the alternative approach conceives of academic autonomy as the freedom *to* pursue knowledge *for* society. The larger transdisciplinary purpose of peer review, according to this alternative account, is not to erect a wall that separates academic knowledge production from its societal use. Instead, peer review should serve to mediate between the values of the free pursuit of knowledge and meeting societal needs. This alternative view rejects the opposition between the internally directed, free pursuit of knowledge (for its own sake) and the externally directed pursuit of knowledge for the sake of society. It is, then, a false dilemma to claim that knowledge is either pursued for its own sake or for the sake of something else.

The incrementalist approach to peer review holds fast to the Humboldtian idea that the infinite pursuit of knowledge is intrinsically valuable. Whatever instrumental value society might gain from this pursuit is secured by pumping knowledge into a reservoir from which society may draw, eventually leading to societal benefits. Knowledge producers need not concern themselves with how society might benefit from the knowledge they produce, and any attempt by society to ask academics to consider societal needs will only interfere with the efficient pursuit of knowledge for its own sake. For these reasons, peer review should take place within the academy, on academic terms, and according to academic (hence, disciplinary) standards.

The alternative approach to peer review revalues the notion of serendipity. According to the Humboldtian-incrementalist approach, serendipity is reduced to blind, undirected luck; and the responsibility for being lucky is largely foisted on society. Academics pursue knowledge for its own sake, and if they happen to produce something of use to society, so much the better. According to the alternative approach to peer review, serendipity is reconceived as sagacity regarding opportunity (Holbrook 2015b). This revaluation of serendipity suggests that academics develop a sensitivity toward recognizing societal needs as opportunities to further their research. Rather than using peer review as a tool to promote the pursuit of academic knowledge for its own sake (and then scrambling to adapt it to interdisciplinary and transdisciplinary demands), this alternative view suggests redesigning peer review as a tool for communication among academics (from whatever discipline) and between academics and members of society. Rather than suggesting them as replacements for peer review, altmetrics can be viewed as an early attempt to redesign peer review as just such a tool for communication.

This alternative view has yet to be developed fully, and in its current state is not without its problems. Academic rigor will have to be reconceived as something that requires more than the approval of one's disciplinary peers. Disciplines will have to relinquish some power over what counts as good research (although this will also serve to respond to charges of conservatism levied against peer review). Academics will have to get over several hurdles, including: the idea that the only sort of freedom possible is freedom from constraints; the idea that serving society renders one servile; and the idea that the highest value is the infinite pursuit of knowledge for its own sake. But perhaps, if we open ourselves up to the pursuit of research for society, we academics will also more effectively counter the current trend toward ever-increasing demands for accountability to society. If we own serendipity as sagacity regarding opportunity, then we give ourselves our own constraints—a process that is entirely compatible with rigorous peer review.

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CHAPTER 35

INTERDISCIPLINARITY IN RESEARCH EVALUATION

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Research evaluation (or quality assessment) means the systematic determination of the merit, worth, and significance of a research activity. It implies the existence of both a judgment of quality and a set of organizational procedures and outcomes that are associated with that judgment (Brennan 2007). The evaluation of interdisciplinary research, however, is a tricky issue. On the one hand, the concept of interdisciplinarity already contains a presupposition that it is a valuable thing, as it offers something that is missed by disciplines. On the other hand, because of its deviation from disciplinarity—one of the conditions of possibility of academic knowledge—its value is somehow dubious. This chapter addresses this dilemma by discussing the expected benefits of interdisciplinarity in knowledge production, and the means and measures by which those benefits may be acknowledged and captured in research evaluation.

Such normative consideration of interdisciplinarity requires a critical awareness of the two principal meanings of the term "discipline": first, it refers to a particular branch of learning or body of knowledge, and second, it refers to the maintenance of order and control (Moran 2002). This echoes the relationship between knowledge and power, which is crucial for considering questions of research evaluation. Evaluation is, in essence, a means of exercising control over knowledge. In the case of interdisciplinary research, however, there is no consensus on the legitimate sources and types of control over it. Underlying the debate are uncertainties that center on the concept of interdisciplinarity itself, which often comes in different variations, such as multi-, inter-, cross-, and transdisciplinarity.

First, it is far from clear what defines the quality (or excellence) of interdisciplinary research. Whenever research crosses boundaries between disciplines, the problem arises that each discipline carries specific and sometimes conflicting assumptions about what constitutes quality. The criteria of disciplinary communities are proving insufficient for research that expands, integrates, or challenges the discipline's own canon. In such intellectual exchanges, what exactly is it that determines the relevant criteria: one's own discipline or the other discipline, or some combination of the two—or perhaps knowledge users outside of academia? Second, and related to the previous point, it is unclear who judges interdisciplinary work. Since there is no clearly defined community of peer reviewers as there generally is for disciplinary research, competent reviewers can be very hard to find. Thus, peer review is

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often biased toward established approaches, unreliable in assessing interdisciplinary work, and helpless in comparing different types of excellence against each other (see Holbrook, this volume). Third, there is no agreement on what constitutes interdisciplinarity, and how it can be identified and measured in practice (Huutoniemi et al. 2010). The definitional debate tends to be paralyzed by the notion that interdisciplinary research can have so many profiles (see Klein 2006, 2008).

The present chapter seeks to address these issues by performing a meta-analysis of the concept of interdisciplinarity in research evaluation. We aim to overcome two major divisions in the existing understanding of the topic. First, there are different normative framings of interdisciplinarity, which shape assumptions about quality and how it is best determined. From this discussion, we identify three major epistemic values or guiding principles of interdisciplinarity and discuss their meaning for research evaluation. Second, there is a growing gap between conceptualizing and measuring interdisciplinarity in research evaluation and the purposes these endeavors have come to serve. Rather than prioritizing one approach over the other, our aim is to bring them together in a mutually reinforcing way. Parallel to the conceptual discussion of the values of interdisciplinarity, we provide bibliometric approaches for mapping and measuring the cognitive properties of research that can be associated with those values. The combination of qualitative and quantitative definitions makes the chapter particularly useful for the purposes of reconsidering and designing research evaluations from an interdisciplinary point of view. The actual implementation of these definitions is likely to differ between particular evaluative settings and is thus beyond the scope of this chapter.

35.1 Epistemic Values of Interdisciplinarity

Evaluations are used, among other things, to certify research activity as valid, to distribute resources in academia, to improve the performance of researchers and organizations, to inform strategic decisions, and to legitimate scientific knowledge in society. Different functions of evaluation raise different questions about interdisciplinarity and offer different kinds of control over knowledge production. In order to better understand and deal with these issues, we review some of the main benefits or "goods" that interdisciplinarity is expected to convey. We are not so much offering a procedure of evaluating interdisciplinary research as giving an epistemic account of what would be involved in doing so.

Interdisciplinarity is not an end itself, but a means of advancing knowledge. To this end, it has several assets that are not, or not appropriately, provided by disciplinary research. In scholarly and policy discussions on the epistemic benefits of interdisciplinary research, three overarching values stand out: breadth, integration, and transformation. Following the standard usage of terms (e.g., Klein, this volume), one might classify research pursuing these values as multidisciplinary, interdisciplinary, and transdisciplinary, respectively. However, our aim is not to provide specific evaluation criteria for different categories, but to illuminate the various "added values" that may and do span those categories. While the primary focus of this chapter is on interdisciplinarity as an academic endeavor, the epistemic values are also relevant for research that involves actors beyond the academic realm. In what follows, we discuss the meaning, implications, and relevance of these values for research evaluation, and summarize them in Table 35.1.

Table 35.1 Three Major Epistemic Values of Interdisciplinarity and Their Implications for Research Evaluation

	Breadth	Integration	Transformation
Value added	Expanded repertoire of specialized expertise	Synthesis of perspectives	Transformation of specialized worldviews
Accountability	Multiple disciplines	Integrative research context	Hybrid communities, future generations
Evaluative focus	Management of diversity	Integrative process	Creativity, renewal of knowledge structures
Epistemic standards	Combination of disciplinary standards	Specific standards for integration	Proactive, emergent standards
Policy implications	Structural flexibility in the evaluation process	An evaluation system of its own	New governance of knowledge production
Proponents	Academic organizations, sociologists of science	Problem-oriented organizations, practitioners, and theorists	University reformers, antidisciplinary movements
Pathologies	Increase of bureaucracy, lack of community	Institutional isomorphism with disciplines, including their limitations	Epistemic anarchy, no cumulative advancement

35.1.1 Breadth

The most common value of interdisciplinary research, compared with disciplinary research, is the breadth of subject matter, vision, or skills: its span of attention extends to more than one discipline, field, or specialty. The flow of ideas and intellectual exchange across fields are promoted to combat the general tendency of disciplines and specialties to become self-referential, monolithic structures. Such dynamics are often deemed a premise of both intellectual development and problem solving, at least in the long term (e.g., Stirling 2007).

In pursuing breadth, specialized expertise is the baseline for assessment, which is guaranteed by the professional accountability of experts to their respective epistemic communities: "A basic premise of quality interdisciplinary work is that it satisfies quality standards arising from the disciplines involved" (Boix Mansilla et al. 2006, p. 73). Keeping disciplinary depth allows scholars to bring their disciplinary specialty to bear in interdisciplinary collaboration. Yet, it places new demands on the organizational arrangements through which an expanded repertoire of expertise is mobilized. The focus of interdisciplinary evaluation is thus on the effective division of cognitive labor across specialties: well-managed coordination, collaboration, and exchange are crucial indicators of successful interdisciplinary work.

The central challenge of evaluating breadth is to include an appropriate range of experts in evaluation constituencies, and to handle their likely disparate inputs into the review process. To avoid cognitive particularism and disciplinary parochialism, reviewers should be open-minded, respectful of various traditions, and tolerant to approaches other than their own.

The participation of researchers in the selection of appropriate reviewers can ensure that all relevant aspects of the work are taken into account. Deliberation among evaluation constituencies is critical to dealing with different judgments and weighting the different disciplinary contributions.

Here, the stance is to ensure fair and competent evaluation for interdisciplinary research within the existing structures of academia. Yet, fairness is not easily achieved. Several empirical studies have illustrated various biases toward established approaches. Interdisciplinarity is easily considered by peer review panels a "plus," but not substitutive for disciplinary markers of quality (Lamont 2009). To expect both disciplinary depth and interdisciplinary breadth in a single research effort is, however, to place unrealistic demands on researchers (Lyall et al. 2011). Competent evaluation of breadth may be difficult to achieve, too, as collective evaluation processes are often characterized by a clear division of scholarly tasks, little interaction, and tacit compromises (Langfeldt 2004). Interdisciplinary considerations, however, can be encouraged by selecting reviewers with sufficiently overlapping expertise and/or personal interdisciplinary competence (Huutoniemi 2012).

Despite these challenges, the breadth of expertise is a highly relevant criterion for evaluating any large-scale project, program, or organization. It emphasizes the need to manage diversity in the increasingly specialized and complex system of knowledge production. However, it does not help institutionalize interdisciplinary scholarship as a distinctive pursuit in its own right, but builds on the strength, flexibility, and self-organization of existing disciplines. Lack of autonomy and authority over evaluation criteria can make interdisciplinary research unrewarding, risky, and vulnerable to specific disciplinary interests. At the same time, its evaluation will require much bureaucratic effort, which is subject to its own problems (see Jacobs 2013).

35.1.2 Integration

Another central value of interdisciplinary research is the capacity to bring together knowledge from disparate fields into a synthetic or coherent whole. This highlights a dimension of interdisciplinarity that is presumed but not problematized in the pursuit of breadth. Synthesis or integration is typically regarded as the distinguishing but elusive characteristic of interdisciplinarity (Repko 2012). Despite the huge variety of interdisciplinary activities, the common bond is often the need to develop an integrated end result, either an intellectual synthesis or a solution to a practical problem (NAS 2005, p. 2). Integration is understood as a means toward greater insight and greater success at problem solving.

The instrumental role of integration in pursuing relevant ends marks a clear departure from disciplinary standards of quality, and provides a point of reference for evaluating the merits of interdisciplinary research in their own right. Underlying this view is the observation that integration is indeed a very complex effort requiring specific concepts, tools, and expertise that cannot be reduced to its disciplinary components. Moreover, it is often critical to integrate knowledge from the field of practical action that the research is related to (e.g., Hirsch Hadorn et al., this volume).

While the conventional standard of scholarship rests on the mastery of an intellectual domain, interdisciplinary scholarship rests partly on procedural and interactional expertise. As integration is a social and cognitive process, a valid assessment must involve some indication of the degree or extent of knowledge integration that occurs while research is being conducted (Wagner et al. 2011). This may require assessment during the research alongside the traditional ex ante and ex post evaluations. The success of interdisciplinary collaboration depends on the coconstruction and sustenance of a shared collaborative space, where emotional and social dimensions intertwine with the cognitive in complex ways (Boix Mansilla et al. 2016).

The pursuit of integration has generated guiding questions for the evaluation of interdisciplinary projects and programs: Is the diversity of disciplines and fields too narrow or too broad for the task at hand? Have relevant approaches, tools, and partners been identified? Has synthesis unfolded through patterning and testing the relatedness of materials, ideas, and methods? Have known integrative techniques been used? Is there a unifying principle, theory, or set of questions that provides coherence? (Klein 2008). As the questions indicate, the evaluation of integration typically takes place "in context": it aims to encompass the various activities of the research group and allow for the influence of relevant stakeholders in the evaluation process (Spaapen et al. 2007).

As a new, integrative mode of scholarship, interdisciplinarity calls for an evaluation system of its own (see Stokols et al., this volume). To make any system of evaluation work, there needs to be a community of practice with shared norms, values, experiences, and referent points. An exemplary description of such as system is Julie Klein's *Creating Interdisciplinary Campus Cultures* (Klein 2010). However, sophisticated criteria for interdisciplinary integration do not solve the problem of how to evaluate new syntheses vis-à-vis more discipline-based accounts of the same phenomena, or for that matter, whether and how to incorporate interdisciplinary values into academia as a whole. There are also dangers in ranking interdisciplinarity in terms of degree to which knowledge from disparate fields is brought together in a synthetic or integrative manner. First, integrated solutions from one point of view are often clearly limited or incomplete from another point of view (Jacobs 2013). Second, integration is by no means the goal of all interdisciplinary work, which may be exploratory or critical in intent (Barry & Born 2013), whereas important intellectual syntheses can occur also within disciplines. Third, the very idea of integration neglects the possibility that knowledge created in different conceptual spaces is incommensurable (Holbrook 2013).

35.1.3 Transformation

The third epistemic value of interdisciplinarity is its potential to transcend or transform the old divisions, disciplines, and dogmas of knowledge (e.g., Barry & Born 2013; Klein 2014). The impetus is that the status quo is not sustainable, as disciplines have failed to understand the pressing challenges of humanity. This stance highlights the fact that knowledge is not separate from politics and action, but influences and is influenced by them. Interdisciplinarity is promoted as a liberating force that challenges the existing structures of knowledge and transcends narrow disciplinary worldviews. It may be associated with critical or emancipatory goals of knowledge, and/or seen as a source of radical innovation and breakthrough.

We call this value "transformation," and detect it behind a heterogeneous set of interdisciplinary activities within and beyond academia. In the past few decades, transformative interdisciplinarity has been extensively justified by political and societal demands (Gibbons & Nowotny 2001). The contextualization of problems in various real-world settings and the public accountability of science are often set directly against the disciplinary model of knowledge production. However, transformation may also result from an initially apolitical attempt to resolve paradoxes, for example, between different epistemologies. Interdisciplinarity can thus facilitate the process through which science transforms its own institutional design and social relations, expanding its problem space over time.

In any case, implications for evaluation are profound. One possibility is moving away from a closed system of quality control toward an open-ended process that is not held captive by the status quo of existing epistemic categories and their constituencies. The worth of interdisciplinary efforts lies not in their consistency with disciplinary or other institutional antecedents but precisely in their capacity to transform them. While given epistemic standards for such efforts do not exist, priority is placed on positively reframing and refocusing how important real-world challenges are addressed. A crucial point is that "the design, implementation and interpretation of the entire research or appraisal process is conducted as an equal collaborative partnership with disparate wider interests *beyond the practitioners themselves*" (Stirling et al. 2015, p. 32, emphasis added). This definition emphasizes the benefits of broadening out and opening up existing understandings.

The evaluation of interdisciplinary transformation requires a proactive stance, including openness to inputs from relevant stakeholders. The inclusion of various stakeholder groups in evaluation is deemed important not so much for ensuring competent evaluation, but for making the epistemic stakes and blind spots visible and open to negotiation. Thus, public engagement is aimed at "giving voice" to those who may have other questions to be answered, other ways of answering them, and other conclusions to draw than one's disciplinary peers (Spaapen et al. 2007). Accordingly, the notion of "peer" is being extended to include all those who have a desire to participate in the resolution of the issue at stake (Funtowicz & Ravetz 1993). Various models of deliberative democracy are used to foster this ideal, such as "consensus conferences" or "citizen juries" (McDonald et al. 2009).

Successfully pursuing and evaluating transformation is confronted with persistent problems regarding the scope of interests and values that are taken into account, and the methods that can be applied to reflexively weigh the evidence of quality. It is not clear that simply extending the stakes involved will make the evaluation process more open to transformative interdisciplinarity. Also the opposite can be the case: There is a danger of politicizing evaluation to the extent that shared epistemic values are overridden by more partisan interests. This, in turn, threatens the internal capacity of scientific inquiry to transform the existing social reality by "speaking truth to power." Moreover, while interdisciplinary transformation is often highly valuable in specific occasions, it builds on and complements the operation of disciplinary science.

35.2 Mapping and Measures of Interdisciplinarity

As a result of the contested nature of interdisciplinarity, qualitative approaches to its evaluation are sometimes dismissed as lacking rigor or being potentially influenced by partisan interests in what constitutes interdisciplinarity and what constitutes scientific quality

(Laudel & Origgi 2006). Quantitative approaches can be helpful in documenting and expanding empirical evidence as well as in providing contrasting perspectives on interdisciplinarity (Rafols et al. 2012). Such evidence may be important in policy dynamics since quantitative approaches are generally seen as more "objective." However, as we will see, mapping and measuring interdisciplinarity depends on very specific choices on classifications and metrics that are value laden even if based on objective evidence. Yet, combined with deliberation on appropriate values, these quantitative tools can enrich the evaluation of interdisciplinary research, for example in terms of transparency.

This section proposes methods for mapping and measuring interdisciplinarity in terms of breadth, integration, and transformation, in order to illustrate the values presented above. We discuss how each of these concepts can be operationalized in various ways depending on the aspects that are considered relevant for a specific evaluation. In addition to indicators, we also propose visualization tools (viz., science maps) that convey a more nuanced understanding than one-dimensional measures of interdisciplinarity (Rafols et al. 2010). The goal of the scientometric analysis is to provide empirical support to the evaluation of breadth, integration, and transformation in a given body of research, which constitutes the "system" under evaluation (e.g., a project, a university, a large collaboration, a funding program).

Visualizations and measures of interdisciplinarity require the use of knowledge classifications, which are quite controversial. One may conceive different perspectives for classifying science: not only disciplinary categories but also, for example, diseases or technological classes. Although user-oriented classifications may play an important role in the evaluation of research impacts beyond academia, they are not yet robustly developed. In this chapter we focus on disciplinary categories that do not capture nonacademic aspects of research.

Underlying a knowledge classification is the notion of "cognitive distance" (Stirling 2007): some categories can be conceived as more proximate or further apart than others. For example, cell biology and biochemistry are understood as more similar (i.e., more proximate in a cognitive space) than cell biology and geophysics. Cognitive distance can be operationalized in terms of the correlations (e.g., Pearson or cosine similarity) of some variables (e.g., citations, word occurrence) of disciplinary categories. We use the convention that the higher the citation correlation among knowledge categories, the more conventional the relation between the categories and thus the closer the cognitive distance.

The sections below explain how measures of interdisciplinarity can be applied for a given body of research that is represented by a set of publications (or other documents) produced by a given organization (a laboratory, a department, a university), a small or large project, or a research area.

35.2.1 Operationalization of Breadth and Integration

We propose to operationalize "breadth" with the concept of diversity (Stirling 2007) and "integration" with a combination of diversity and coherence (Rafols et al. 2012). Diversity aims to capture the distribution of elements (e.g., researchers, publications, financial resources) across categories (e.g., disciplines) for a given body of research. Coherence describes the extent to which elements of different categories are related, for example via interactions between researchers, via exchanges of information such as letters or e-mails, or

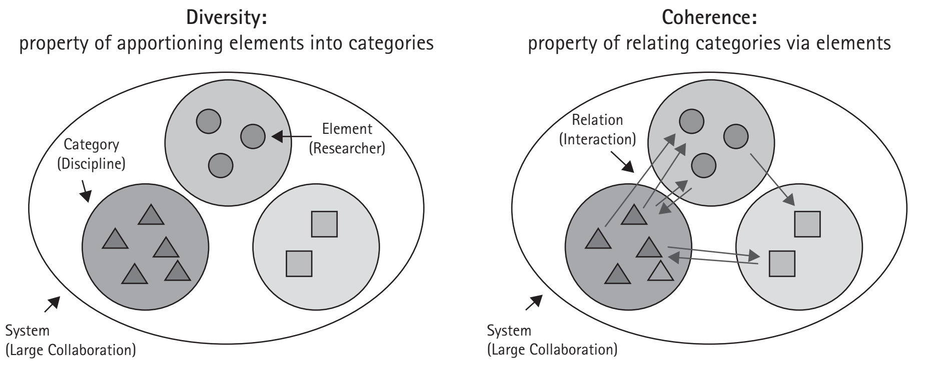

FIGURE 35.1 Illustration of diversity (left) and coherence (right). Large circles represent categories. Small figures represent elements of a specific category (triangles, circles, squares). In parentheses, an example of operationalizing the concepts in the evaluation of a large collaboration: Diversity refers to the allocation of researchers (elements) across disciplines (categories), and coherence refers to the cross-disciplinary interactions among researchers.

Source: Based on Rafols (2014).

via citations. Figure 35.1 illustrates the two concepts. "Integration" is characterized both by high diversity *and* high coherence, because it implies that linkages are made between somewhat disparate elements.

The mathematical operationalizations of diversity and coherence are not unique. As illustrated in the left side of Figure 35.2, diversity can increase when the number of categories increases (variety), when the distribution of elements across categories become more even (balance), or when the elements are distributed across more distinct categories (disparity) (Stirling 2007). Also, as illustrated in the right side of Figure 35.2, coherence can increase

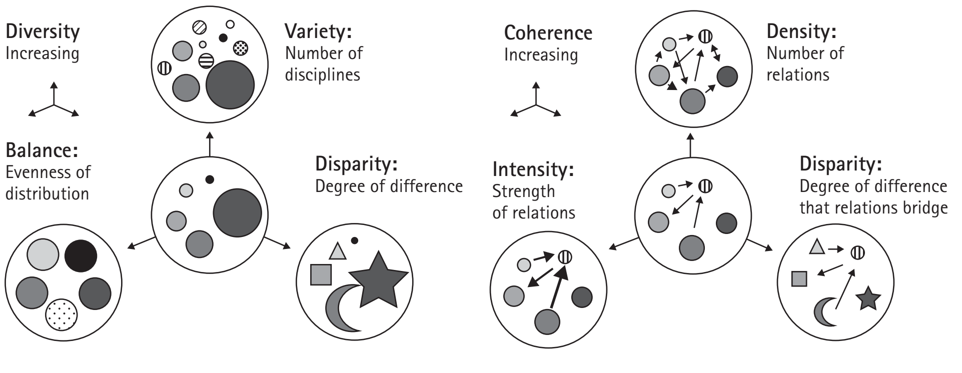

FIGURE 35.2 Schematic representation of the attributes of diversity (left) and coherence (right). Each full circle represents a system under study. The figures inside the circle are the categories into which the elements are apportioned. Different shapes indicate more difference between the categories. The size of the figures indicates the proportion of elements in a category. Thicker lines indicate higher intensity in relations.

Source: Based on Stirling (1998) and Rafols (2014).

Table 35.2 Measures of Diversity and Coherence

Notation	
Proportion of elements in category *i*:	p_i
Intensity of relations between categories *i and j*:	i_{ij}
Cognitive distance between categories *i* and *j*:	d_{ij}
Diversity Indices	
Generalized Stirling diversity	$\sum_{i,j(i \neq j)} \left(p_i p_j\right)^{\alpha} d_{ij}^{\beta}$
Variety ($\alpha = 0, \beta = 0$)	N
Simpson diversity ($\alpha = 1, \beta = 0$)	$\sum_{i,j(i \neq j)} p_i p_j$
Rao-Stirling diversity ($\alpha = 1, \beta = 1$)*	$\sum_{i,j(i \neq j)} p_i p_j d_{ij}$
Coherence Indices	
Generalized Coherence	$\sum_{i,j(i \neq j)} i_{ij}^{\gamma} d_{ij}^{\delta}$
Density ($\gamma = 0, \delta = 0$)	M
Intensity ($\gamma = 1, \delta = 0$)	$\sum_{i,j(i \neq j)} i_{ij}$
Coherence ($\gamma = 1, \delta = 1$)*	$\sum_{i,j(i \neq j)} i_{ij} d_{ij}$

*These are the most parsimonious measures capturing the various properties of the underlying concepts.

Box 35. 1 How Science Maps Can Inform Evaluations

Figure 35.3 illustrates the disciplinary diversity (breadth) and coherence (integration) of an institute (ISSTI, The Institute for the Study of Science, Technology and Innovation, University of Edinburgh).

It captures the three properties of diversity: (1) the number of circles reveals the variety of disciplinary categories; (2) the relative size of the circles shows whether the citations are concentrated in a few disciplines or are more evenly spread (balance); and (3) the distance between the circles tells whether the publications spread over very different research areas (disparity of distribution).

Also, the viewer can intuitively become acquainted with the notion of coherence: (1) the number of lines illustrates the density of citations; (2) the thickness of lines reveals the intensity of citations across disciplinary categories; and (3) the distance crossed by the lines shows the disparity of links—that is, if citations are made across fields that do not often interact and therefore lie far apart in the map of science.

As shown in Figure 35.3, one can compare the observed citation patterns with the expected citation patterns for a specific publication set, and see whether the observed patterns stand out as more dense, more intense, or more disparate than the expected patterns. Thus, the figure conveys information on the extent to which the organization under assessment is realizing certain values of interdisciplinarity.

when the number of relations increases (density), when the relations become stronger (intensity), or when they link more different categories (disparity) (Rafols 2014).

Any single index of diversity captures the three different properties of variety, balance, and disparity but may weight them differently. Likewise, any measure of coherence makes an implicit choice of the relative weight of density, intensity, and disparity. Following Stirling (2007), we have proposed generalized heuristics and measures for exploring diversity and coherence as shown in Table 35.2 and discussed in Rafols (2014).

Breadth and integration are operationalized here at a high level of abstraction in order to allow for using various data sources and fit to different contexts. Bibliometric data can be used to calculate the various measures, including cognitive distance, which is difficult to estimate without structured data (Rafols et al. 2012).

Visualizations can be very helpful in conveying information on diversity and coherence without complex mathematics (see Box 35.1). This is illustrated in Figure 35.3, which shows the citations made by the publications of a research institute (ISSTI, University of Edinburgh). This information illustrates areas in which ISSTI is active, and how ISSTI is unique in linking disparate disciplines in comparison with conventional patterns. Evidence of such linkages enables, for example, deliberations about the success of a project in making specific connections between, for example, management and energy research.

35.2.2 Operationalization of Transformation

Transformation is more difficult to map and measure than breadth and integration, because, by definition, it cannot be captured by preexisting disciplinary categories. Conventional disciplinary categories are based on institutionalized classification systems, which are slow to capture changes in the knowledge landscape. Using old disciplinary categories over new knowledge may create measurement artifacts. It is thus necessary to create descriptions of the scientific landscape that are sufficiently fine-grained to capture developments that fill up previously empty cognitive spaces or change the overall knowledge structure. Thus, it becomes necessary to use units of analysis such as research specialties or research topics rather than disciplines. Journals can be used for some purposes, but they are sometimes problematic because many important journals cover several specialties and topics. Co-word maps, topic modeling, or small topic clusters may provide a richer, more fine-grained and more reliable base for knowledge landscape to capture transformations.

One way to spot the transformative nature of an interdisciplinary effort is to check whether it falls outside the main disciplinary concentrations. This is illustrated in Figure 35.4 for the case of management and innovation studies. The journal maps show areas of high density that correspond to the disciplinary cores of management and economics. The areas of low-density zone are journals related to science, technology, and innovation, which are less dominant and can represent a transformation of the landscape. Ideally, one would look at these maps over time to see how the landscape is developing. But with a static map such as this, one may hypothesize that publications in the interstitial or peripheral areas are more related to efforts to transform science than those in the disciplinary cores. The overlay maps of ISSTI and London Business School (LBS) show contrasting patterns of publication: ISSTI publishes in more transformative areas, whereas LBS publishes mainly in the disciplinary cores. This information can be useful in evaluations that aim to trace interdisciplinary transformation.

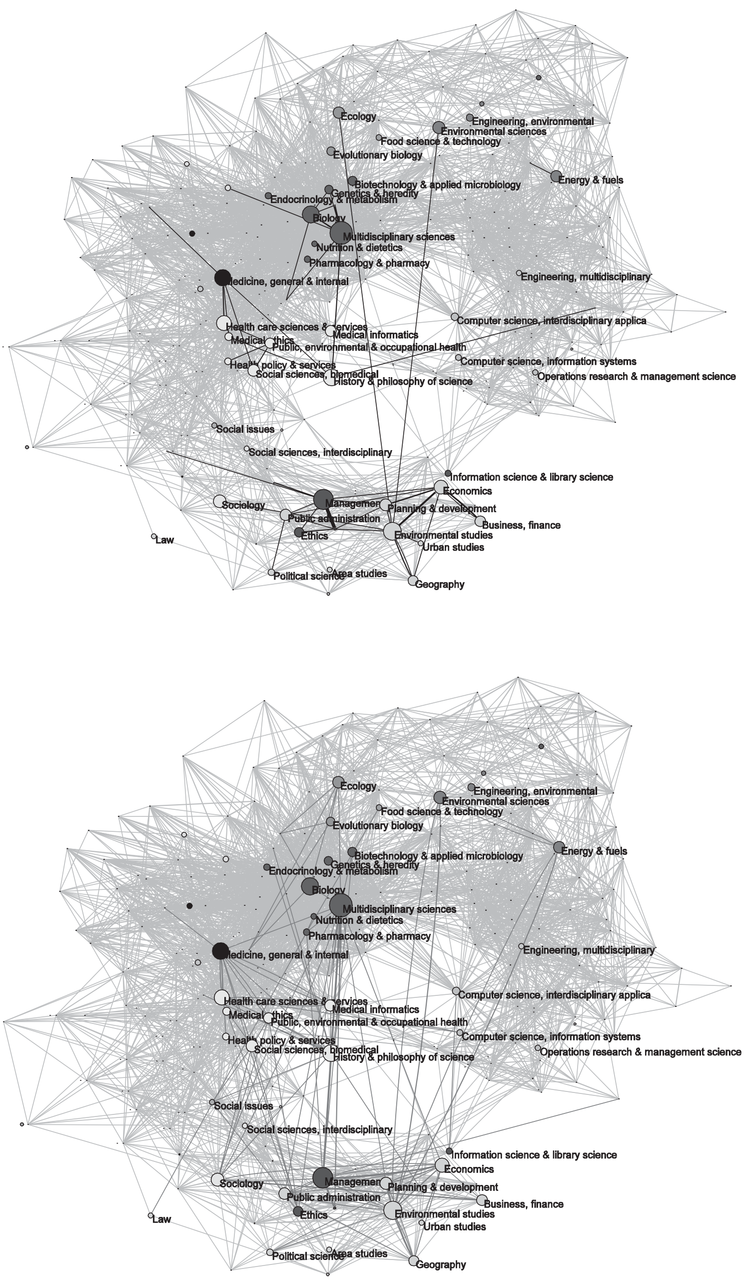

FIGURE 35.3 Expected (top) and observed (bottom) citations of the research center ISSTI (University of Edinburgh) across different Web of Science categories. The gray lines in the background position disciplinary categories in the global map of science (Rafols et al. 2010). The size of the nodes illustrates the aggregate number of citations given to a category from all ISSTI's publications (2006–2010). Lines in the top figure show the expected citations between the specific categories in which ISSTI publishes. The computation of expected citations is based on the total number of publications in a category, and the average proportion of citations to all other fields. It can be observed that the expected citations tend to be within disciplines: within biological sciences, within health services, and within social sciences. Lines in the bottom figure show the citations between fields observed in ISSTI's publications.

Source: Rafols et al. (2012)

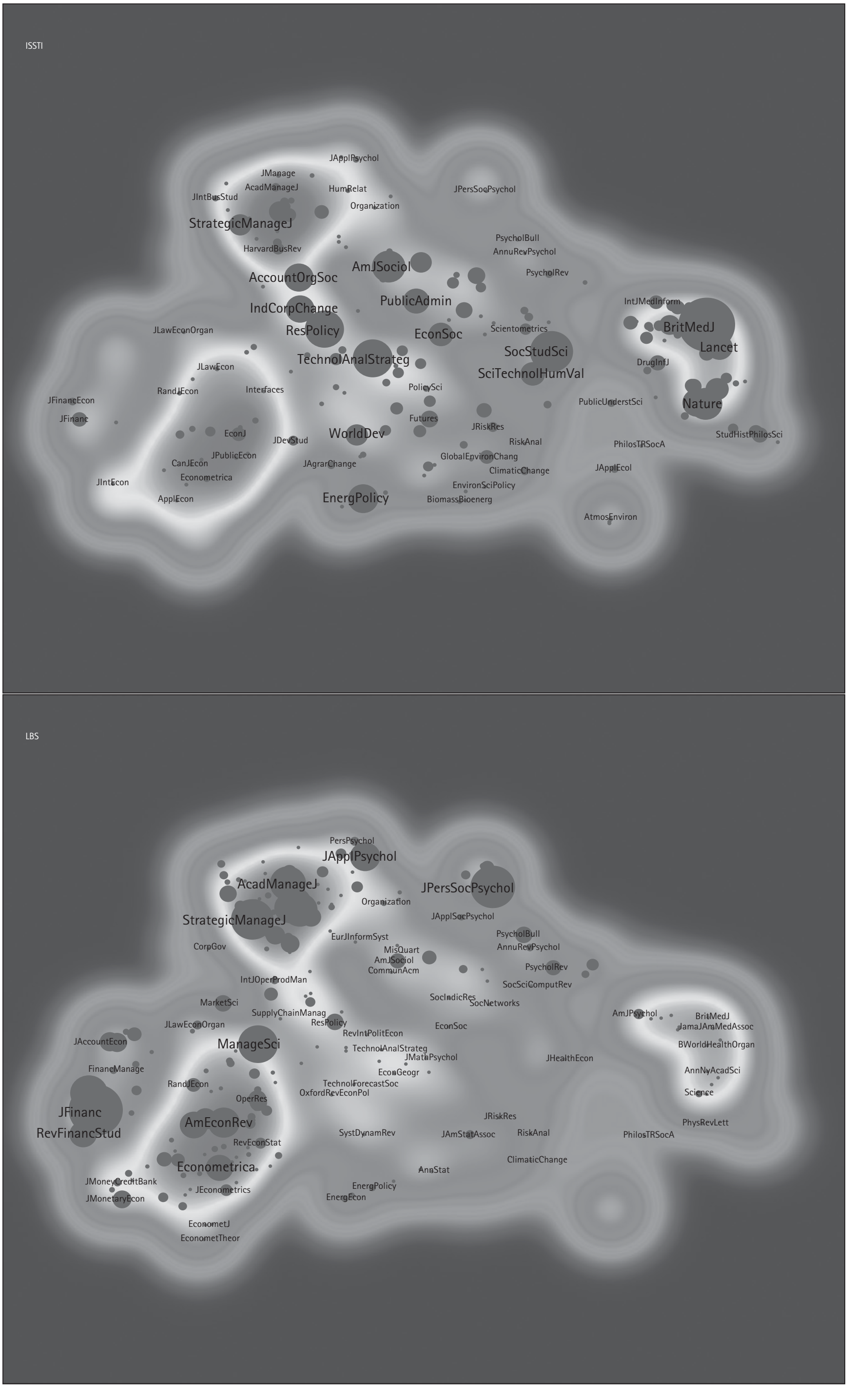

FIGURE 35.4 Overlay of the references (gray nodes) of the research center ISSTI (University of Edinburgh) and London Business School (LBS) publications over a journal map. The map illustrates the similarity structure of the 391 most important journals in management and innovation studies. The size of gray nodes indicates the proportion of the research unit's references in a given journal. Journals located in between red areas, that is, between disciplinary cores, are interpreted as potential areas of transformation. Please go to figure in the source so as to see the original figure with color.

Source: Rafols et al. (2012)

35.3 Conclusion

As suggested at the outset, the evaluation of interdisciplinary research is complicated by ambiguity about what interdisciplinarity is and what it should be. We have addressed this problem by analyzing the major expectations of interdisciplinarity in both qualitative and quantitative terms. First, we have discussed the various ways interdisciplinarity can add value to the disciplinary organization of academia and their respective implications for research evaluation. Second, we have provided tools for mapping and measuring these value-added properties and illustrated what kind of evidence they can convey to evaluation.

The combined examination of values and indicators allows us to gain a more differentiated understanding of what exactly to look at when evaluating interdisciplinary research. The first step of the evaluation of interdisciplinary research, we suggest, is to consider the relevance of the various values that interdisciplinary interaction involves (e.g., breadth, integration, transformation). The second step is to select the categories of knowledge (e.g., disciplines, research specialties, technology classes) that can be used as reference points in detecting those interactions. The third step is to select the unit(s) of analysis (e.g., researchers, publications, financial resources) that represents the knowledge base of the given entity (e.g., a university, a network, a funding program). The final step is to enquire into the degree and form of interdisciplinarity in terms of the diversity, coherence, and/or transformation of the selected units.

In the literature, it is often acknowledged that interdisciplinarity is not driven by a single goal, and that the variability of goals, in turn, drives variability of criteria and indicators of quality (Klein 2008). In this chapter, we have aimed at a more systemic view of the benefits and indicators of interdisciplinarity. The central values of interdisciplinarity are not exclusive to interdisciplinary activities only, but clearly resonate with the overall goals of science. At the same time, interdisciplinary research is in a good position to advance these goals.

The degree of emphasis placed on each value depends on the purpose of a given evaluation. Measures and maps are only supportive tools in order to trace the values. Research evaluation is used for so many different purposes and in so many different scopes, levels, and contexts that we have deliberately not addressed such issues here. Beyond any particular perspective, however, evaluation is worthy of attention because it is an important part of the way in which science is being shaped and changed today. The incorporation of interdisciplinary concerns in research evaluation is one the most significant dynamics of such change. An implication of this dynamic is increasing awareness of disciplinary discrepancies, ambiguities, and ignorance, pointing to the need to go beyond disciplinary criteria of validating knowledge. Interdisciplinary considerations in research evaluation, therefore, are relevant and consequential for disciplinary research, too, and should become a routine part of quality control in science (Huutoniemi 2016). At the same time, criteria for interdisciplinary research need to be subjected to critical examination in terms of their systemic effects beyond the particular purpose they are designed to serve.

More explicit discussion of the various purposes and diverse beneficiaries of interdisciplinary evaluation, especially vis-à-vis disciplinary evaluation, is needed for making robust decisions on which values count in specific situations and how their realization can be measured. As we have seen, breadth, integration, and transformation are not equally relevant criteria for all purposes of evaluation, but highlight different, though not incompatible, normative goals. Similarly, the selection of quantitative tools to gauge interdisciplinary properties depends on a number of decisions that are both value-laden and significant for the kind of interdisciplinary relationships that are recognized.

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CHAPTER 36

THE CHALLENGE OF FUNDING INTERDISCIPLINARY RESEARCH

A Look inside Public Research Funding Agencies

THOMAS KÖNIG AND MICHAEL E. GORMAN

Interdisciplinarity has become a prominent concept in science policy, not least because it encapsulates a powerful promise: By overcoming the traditional (and atavistic) boundaries erected by the disciplinary organization of science, scientific research can contribute better to the societal challenges that humankind faces. As "boundary organizations" between science and policy (Guston 2000), public funding agencies have been obliged to take up such a powerful concept. Complementing the more theoretical contributions in this volume addressing policy issues, in particular those on peer review (Holbrook, this volume) and on evaluating interdisciplinarity (Huutoniemi & Rafols, this volume), this chapter takes a comparative look at how interdisciplinarity is defined at two funding agencies supporting academic research, the European Research Council (ERC) and the US National Science Foundation (NSF).

36.1 Interdisciplinarity as a Challenge

In an ever-growing landscape of funding opportunities, this may at first appear an odd choice, since there are many instruments and agencies specifically dedicated to fostering various kinds of interdisciplinary research today (Heinze 2008). Yet, funders dedicated to the more traditional mission, such as the NSF and ERC, remain on top of the pecking order of funding opportunities due to their high reputation among (academic) researchers. However, a brief glance on their websites shows that even traditional funders across the

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world have all subscribed to the idea of privileging interdisciplinary research.[1] The newly founded Global Research Council, a paramount organization within science and engineering funding agencies from around the world, explicitly states that its "participants should recognise and encourage interdisciplinary research where appropriate," and that "researchers should be given opportunities to explore interdisciplinary approaches and engage in emerging fields" (Global Research Council 2013).

The peculiar challenge for this specific (yet highly visible and most respected) set of agencies is to assure their constituencies that, in the midst of the specific request for interdisciplinarity, the allocation of funds remains true to the intrinsic values of scientific quality. These values are traditionally reinforced by disciplinary communities steeped in scientific methods. How are agencies funding basic academic research to deal with this challenge? Comparing the ERC and NSF in terms of this question promises insights into the task of operationalizing interdisciplinary research that go beyond the mere analysis of instruments specifically dedicated to foster interdisciplinarity.

The definition of interdisciplinary research takes place within two (complementary) ambitions. The first concerns the goal of eliciting proposals that embody the property of interdisciplinarity. For example, the ERC publicly encourages "proposals that cross disciplinary boundaries, pioneering ideas that address new and emerging fields and applications that introduce unconventional, innovative approaches" (ERC 2015). The second concerns the task of identifying proposals that are interdisciplinary. To that end, the NSF describes its mission as ("in addition to funding research in the traditional academic areas") supporting "'high-risk, high pay-off' ideas, novel collaborations and numerous projects that may seem like science fiction today" (NSF 2014a). Focusing on how the funding agencies promote and identify interdisciplinarity, this chapter looks at specific policies (instruments, rules, procedures) that are put in place for allocating public funds to research projects. It should be noted that we are not attempting to find out whether the funding agencies are actually supporting interdisciplinary research. As tempting as that question may be, it is beyond the scope of this chapter.

Funders are usually quite secretive with relaying information about their work (Gurwitz et al. 2014). However, the authors have both been working at funding agencies for several years, one as program director at the NSF, the other as scientific advisor to the President of the ERC. This contribution thus draws on our personal experiences as much as on the public statements provided by the two organizations. In the next section, a few words need to be said about funding agencies in general (their history and their specific role in science policy), and the two agencies selected for comparison. After briefly reviewing their respective political and administrative context and their organizational structure, the two agencies are then compared in terms of their available funding instruments as well as their decision-making procedures. Which instruments are available for evoking interdisciplinary research? How are the selection procedures devised in order to be receptive to interdisciplinarity? The chapter ends with some general findings on the working definition of interdisciplinarity at funding agencies more generally.

[1] Specifically, the websites of the National Institutes of Health (NIH) and NSF in the United States; the German Research Agency (DFG), French National Center for Scientific Research (CNRS), British Research Councils (RCUK), and ERC in Europe; and the Japan Science and Technology Agency (JST) all explicitly mention interdisciplinary research.

36.2 Comparing Agencies for Funding Academic Research

Vannevar Bush used a kind of probabilistic reasoning to justify the societal benefits of science in his report *Science: The Endless Frontier*: "Statistically it is certain that important and highly useful discoveries will result from some fraction of the undertakings in basic science; but the results of any one particular investigation cannot be predicted with accuracy" (Bush 1945, p. 19). One of the societal benefits of science was illustrated by the Allied victory in World War II, where the rapid mobilization of science for the war effort was given much of the credit. Sarewitz refers to the assumption that eventually basic research will create benefits for the greater good as a "leap of faith" (Sarewitz 1996, p. 10). For Sarewitz and others, the leap of faith included the idea that advances in science and technology would automatically lead to public benefit.

In 1950, following Bush's recommendation, the United States set up the National Science Foundation. The assumption that funding "pure" science would produce social benefits then spread to the rest of the Western world. Funding agencies have become a common feature of industrialized nations, as agencies similar to the NSF were established in many other industrialized countries, directed at funding "basic research," mostly at universities and other nonprofit research institutes. Over the following decades, as more and more public funds were made available for research, the funding instruments diversified and accountability measures were tightened. The creation of the broader impact criterion for funding at the NSF in 1997, and similar efforts in the Netherlands in 2008 and Canada in 2009 showed that scientists are increasingly expected to consider societal impacts when applying for research funding (Holbrook 2010). For example, the US cross-agency National Nanotechnology Initiative deliberately devoted a small portion of its annual funding to exploring the societal dimensions of advances at the nanoscale, which included ethics, public participation, and promises of job creation (Roco 2011).

The crumbling of faith in the autonomic benefits of funding academic research does not mean that this funding has disappeared from budget lines of national governments; nor did its agencies dissipate into thin air. Today, the NSF is a globally venerable agency for funding primarily academic research. It remains a role model, with the ERC (among others) explicitly modeled after it. Both NSF and ERC promote academic research, that is, research primarily hosted at universities and other nonprofit research institutes and cover most areas of science, including also social sciences.[2] Their reputation in the academic world is due to their (relatively) deep pockets of funding and due to their high standards of peer review procedures. However, there are also major differences between the two agencies. As Table 36.1 indicates, the NSF is substantially larger than the ERC in terms of staff, budget, and the amount of proposals to be processed annually. The difference in size is an important reason for the organizational differences between the NSF and ERC; however, similarly

[2] In the case of the NSF, medical sciences are not part of the funding portfolio; in the case of the ERC, research related to nuclear energy is excluded. Unlike the NSF, the ERC also funds research in the humanities.

Table 36.1 Comparison of ERC and NSF along Indicative Numbers

	NSF	ERC
Budget (approx., in Bio)	$7,1	€1.7
Staff FTE (2014)	1.400	380
Annual no. of proposals submitted (approx.)	50.000	10.000
Annual no. of proposals funded (approx.)	11.000	1.000

Numbers based on the most recent Financial Report and Proposal Guide by the NSF (2014b, 2014c) and the Annual Activity Report by ERC Executive Agency (2014).

important is the specific administrative context of the two agencies, as this has important effects on their identity and, consequently, on their approach toward a working definition of interdisciplinary research.

The NSF is a stand-alone agency within the broader administrative landscape of the United States, reporting to the legislative body (the US Congress). Its mission, according to its website, is "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense" (NSF 2014a). The NSF fits into a complex structure of different funding agencies and priorities. The primary funder of health research in the United States is the National Institutes of Health (NIH), at $31 billion a much larger and more complex organization than the NSF. Academic research relevant to defense is carried out by the Defense Advanced Research Projects Agency (DARPA). Other agencies like the Department of Energy also fund research. In the US context, inter-agency cooperation is generally possible but difficult, because agreements are required, the agencies often have their own peer or expert review processes and the focus in most bureaucracies is inward, on maintaining one's own program and its source of funding.

While the NSF has been historically among the first players in the field of research funding in the US polity and constitutes a full-fledged organization on its own, the ERC is a latecomer to the European stage and, organizationally speaking, a hybrid. Set up in 2007, its founding idea was to extend the then-established research funding policy at European level, namely, to fund primarily collaborative research across European nation-states. The ERC was entitled to focus on "excellence" with no further strings attached (Council of the European Union 2006). However, the ERC was integrated into the European Commission's Research Framework Programme (RFP), currently in its eighth edition, called "Horizon 2020". With the notable exception of its "Scientific Council", a group of independent scientists responsible for crafting the agency's scientific strategy, the ERC is rather a specific instrument of a larger policy framework for research funding.[3]

[3] Hence, while the NSF has to legitimize its spending on an annual basis, and is relatively "free" to fight for its budget (Sarewitz 2007), the ERC is in the more comfortable situation of commanding a budget allocated over a period of seven years through a complex negotiation process between Commission, EU member states, and the European Parliament.

Although hailed as something completely new in the European context, the ERC actually means a return to the old principles of Vannevar Bush. However, its core missions are distinctively narrower and also more instrumentalist than the NSF's. To begin with, the ERC is expected to foster competition among academic researchers (and research institutions) across the continent. In addition, the European Commission perceives the ERC both as an innovator from within (helping to curb excessive regulations and red tape of the RFP) and as a marketing device (improving the overall reputation of the RFP) (König 2016). As a consequence of its strategic positioning, the ERC has always been careful in emphasizing its difference to the rest of the larger policy framework to which it belongs; hence, joint initiatives with other programs of that framework do not exist at all.

36.3 Instruments for Promoting Interdisciplinarity

The NSF describes its organization as "structured much like a university" (NSF 2014b, p. 10). Its seven "directorates" (Biological Sciences; Computer & Information Science & Engineering; Education and Human Resources; Engineering; Geosciences; Mathematical Sciences; and Social Behavioral & Economic Sciences) are divided into divisions, and under each division are programs devoted to specific communities. For example, the "Science, Technology & Society" program (where Gorman worked as a program director) is part of the Social and Economic Sciences Division, which, in turn, is part of the Social, Behavioral and Economic Sciences Directorate. The ERC, on the other hand, is not plotting the division of academic disciplines onto its organizational structure: There is one "scientific department" for managing the entire allocation of funds. The diversification of scientific and scholarly research is taken into account by three domains and a total of 25 panels with the aim of bundling academic disciplines into larger (and per se interdisciplinary) entities.

Keeping in touch with scientific advancement is perceived as crucial in both agencies. The NSF claims to fully include the scientific communities: Up to one-third of that part of the NSF staff that handles research proposals consists of "rotators," scientists who, after a few years at the agency, will return to their research institution. By doing so, the NSF infuses experts with fresh perspectives into the NSF's bureaucracy with the hope to quickly react to emerging fields of research, which often involves interdisciplinary approaches. The ERC is more restricted in that respect. Staff is appointed through formalistic procedures imposed by the European Commission, which usually does not provide the opportunity for researchers to join the ERC and return to their academic hosts later. "Seconded experts" from national funding agencies and ministries are only a handful at a time. Instead, panel members and, as a distinctive subgroup, panel chairs, who are appointed for several years, have grown into trusted informants and play an important role also for reacting quickly toward new, and interdisciplinary, approaches.

In order to operationalize their funding activities, funding agencies have developed a unique set of instruments. Those funding streams (or "calls," or "programs") broadly define the direction of a given amount of money for a specific field of research. In addition, they also determine the field(s) of research within which a proposal can be submitted, the type and extent of research, and the eligibility criteria for proposers. Funding streams are the most powerful levers for allocating funds to a certain kind of research, and their implementation is also an important means for defining what is expected to be interdisciplinary research. To do so, they have three separate options (although they can be combined): Either an instrument prescribes collaboration between researchers with different scientific background, or it issues research topics that need to be tackled through interdisciplinary approaches, or it provides funding for research focusing on translating fundamental research into societal (economic) benefits (more properly called transdisciplinary research).

The implementation of funding streams depends on the specific organizational constraints and contexts of the agencies, and the NSF and ERC are fundamentally different in this respect. As a long-standing organization, the NSF has developed many instruments and also engages in many fields of action, which encompass research and related activities such as conferences, education and human resources, research infrastructures, and facilities construction (NSF 2014b, pp. 57–67). Accordingly, the grants range from support to conferences and workshops through research projects running for 3 years up to creating large-scale research centers; funds differ between low five-digit figures and massive, multi-million-dollar investments.

The rather fine-grained compartmentalization of the NSF carries the threat of missing emerging fields between the established disciplines. Thus, when it comes to promoting interdisciplinarity, the NSF has developed several approaches. It has made provisions that many of its instruments can also be used specifically for fostering interdisciplinary research. The NSF's individual awards (the most common funding type) often include co-principle investigators (co-PIs) and in many cases, these co-PIs come from other fields (Gorman et al. 2013). The NSF programs can issue "Dear Colleague" letters that call for funding in specific areas, and these areas are often interdisciplinary in nature. In addition, there are also different instruments available that are devised to bridge the organizational divisions, and to foster collaboration between scientific fields.

For example, the NSF funds research centers that tackle initiatives too large for one or even several investigators; these centers often are interdisciplinary. The "Integrated Graduate Education and Training" award program (1997–2012) was designed to give graduate students integrated training across research programs from different disciplines or subdisciplines; this program has been succeeded by an NSF Research Traineeship Program, which could be either disciplinary or interdisciplinary. Finally, the NSF's creation of a special program in the "Science of Science and Innovation Policy," which of late has been dominated by economists, and also the new "Division of Industrial Innovation and Partnerships" are evidence of the need to address the political pressure to facilitate the translation of academic research into economic benefits.

The situation is different with the ERC, which is constantly at pains not only to distinguish itself from the rest of the European Commission's RFP but also not to appear as a rival to the long-existing national funding agencies and research councils established in many European countries. With the promise to "keep it simple," the ERC has successfully established a niche in the richly populated landscape of funding opportunities; however, this comes at the price that the ERC restricts its funding basically to one type of grant for individual principal investigators, attached with generous funding in the size of between 1 and 3 million Euros (*ERC* 2014).

While the NSF runs dozens of calls per year, the ERC has established a firm annual routine of three calls, one for each of its three major funding streams, all of which are based again on the same grant type mentioned before. The three funding streams differ only according to different career stages, called "starting," "consolidator," and "advanced" grants. Each stream is organized around the same set of 25 panels (ten belonging to the domain of Physics and Engineering, nine to the Life Sciences, six to the Social Sciences and Humanities). Each panel typically encompasses several scientific disciplines; it is this organizational principle alone that is expected to incentivize submission of interdisciplinary proposals. No further instrument for specifically promoting interdisciplinary research has been established, with two notable exceptions: The ERC "Synergy Grant" invited several PIs to jointly conduct research on large-scale projects; it ran for only for 2 years (2012–2013). One reason for withdrawing the stream was the fear of being perceived as going back to prescribing collaborative research funding, which the rest of the RFP was doing. Similarly to what was said about the NSF, the ERC also runs a specific program, the "Proof of Concept" scheme, providing add-on funding exclusively for ERC grantees to "verify the innovation potential of ideas arising from ERC funded projects" (*ERC* 2014, p. 35).

36.4 Identifying Interdisciplinarity

Funding streams can help to promote interdisciplinary research; however, funding agencies also need a mechanism to identify it. Whatever the shape of the funding stream, the decision-making process underneath is pivotal, as it gives legitimacy to the final decision of which proposals are funded (and which not). As much as the two agencies differ in regard to the funding streams that they command, both firmly rely on same decision-making principle, called peer review, or merit review, the latter being the notion preferred by the NSF (Holbrook, this volume). The decision on funding relies on the assessment of the proposals by a group of academic experts (the reviewers) who are given guidelines to identify and compare the quality of the submitted proposals.

The three most sensitive aspects of operationalizing the peer review principle concerns the criteria along which proposals are valued, the experts (peers) who are invited to do this valuation, and the way the ratings of the experts are channeled into a funding decision. Obviously, all three aspects are also crucial for identifying interdisciplinary research: Criteria can nudge reviewers to value a given proposal against this specific quality; reviewers with broad expertise and research experience may have a better understanding of what to look for; and bringing together the opinion of reviewers with different backgrounds may contribute to a decision that is more balanced with regard to the scientific qualities of the proposed projects.

As noted above, the difficulty for funders here is that, while they want the reviewers to assess the scientific quality of a proposal, they are aware of the fact this usually depends on standards intersubjectively framed in terms of academic disciplines. Hence, both agencies specifically address interdisciplinarity in their versions of the evaluation criteria, thereby forcing reviewers to take this feature into account when assessing proposals. The ERC asks to what extent a proposed project embraces "novel concepts and approaches or development across disciplines" (ERC 2014, p. 31); the NSF wants to know the extent to which "proposed activities suggest and explore creative, original, or potentially transformative concepts" (NSF 2014b, p. 80).[4]

When it comes to the tasks and profiles of reviewers, the similarities between the agencies dominate. Both distinguish between panel members and external reviewers. The external reviewers—whom the NSF calls "ad hoc reviewers," and the ERC "remote referees"—are usually asked to assess only one or several proposals, and depending on their expertise, while the panel members have a more prominent role. Typically, their profile is that of senior scientists and distinguished members of their scientific community; they are expected to have a broad knowledge of their discipline and, if possible, also some experience in interdisciplinary research. To stock their panels with qualified scientists, both agencies have put in place a (mostly informal) infrastructure for recording the qualification, productivity, and impartiality of previous panelists, as well as a (similarly informal) communication web to trusted members of the scientific communities for identifying potential new panelists. At the NSF, the program directors have primary responsibility for recruiting both external reviewers and panelists. At the ERC, the selection of panelists is firmly in the hands of the Scientific Council, with only the (less influential) "remote reviewers" being identified by panel members and scientific officers.[5]

Panelists are considered to be more important simply because both agencies rely mostly on review panels in their decision-making.[6] Panels are generally expected to provide more reliable and better ratings than reviewers, in large part because panelists are used to the ranking system and make decisions based on panelwide discussions (Klahr 1985). The panelists collectively decide what is fundable, based on their reading of the

[4] It should be noted that the formulation of evaluation criteria are differently organized at the two agencies. The NSF sees its overall review criteria revisited in response to organizations like the President's Council of Advisors on Science and Technology (PCAST); they are subject to an ongoing political dispute with the legislative body, the US Congress, on the one hand, and the scientific community, on the other (Holbrook & Frodeman 2012). This is not the case in Europe. Here, the ERC Scientific Council has the ultimate say about the content of the criteria. There is no public discussion on them, nor is their formulation subject to any political interventions, and the review criteria are annually reformulated by the ERC.

[5] However, the ERC's job of identifying the best panel members is not so straightforward. Serving 28 European countries, the ERC is under scrutiny to maintain the impression that, by appointing panelists not only from a wide range of disciplines, but also balanced along gender and nationality, the decision-making process is not somehow privileging one country's scientific community over another. Although this is not communicated to the public, the ERC has imposed guidelines according to which panels have to be balanced (e.g., in order to have no more than three representatives from British universities in one panel). In this context, the goal to identify open-minded, unbiased experts, is competing with other, more formal requirements, an issue that makes the commanding people of the ERC rather uneasy.

[6] It should be noted in passing that some NSF programs use only panels and others just outside reviews. Also, formally speaking, granting is in the hands of leading administrators at both agencies. However, several safety measures are put in place to justify such an extraordinary move, and it thus happens only on rare occasions.

outside reviews and their conversations among each other. Because they provide space where incommensurable expertises are brought together in a "trading zone" (Gorman 2010), panels are also expected to do a better job at identifying (and appreciating) interdisciplinary research.

36.5 Findings

When expected (or even explicitly tasked) to fund interdisciplinary research, funding agencies have to operationalize it within their own means and constraints. By doing so, they inevitably set precedents of what interdisciplinary research may look like. Their working definition becomes the blueprint for proposals submitted for funding, and also for the way those proposals are valued. Even if it was unintentional, funders have become powerful players in shaping the common understanding of interdisciplinarity (Lyall et al. 2013, p. 67). Organizational constraints, funding instruments, and the sensitive elements of the decision-making procedure are pivotal for understanding how funding agencies across the world tackle interdisciplinary research.

When it comes to promoting interdisciplinary research, the NSF has far better means due to its well-established links to the scientific communities and its diversified portfolio of instruments, which are fine-tuned to address different scientific communities, different types of research and research-related activities, and researchers at different career stages. Specifically, the NSF issues calls for interdisciplinary research that are identified in a solicitation or a "Dear Colleague" letter. Thus the NSF can promote interdisciplinary research by asking either for collaboration, by prescribing research topics, and by requiring translation of research into economic benefits.

The ERC does not possess the same range of options. Mostly because of the need to distinguish itself from the funding framework of which it is a part, it is reluctant to prescribe either collaboration or specific topics, and, despite political pressure, it also restricts the translation of research to a narrow aspect of its operations. Instead, the ERC follows a one-size-fits-all approach, promising to treat all research proposals alike. The difference between the two agencies can be described this way: Due to its rich set of provisions and instruments, the NSF supports the scientific communities with tailored funding, while the ERC, due to the fact that it is less autonomous but also seeks to distinguish itself from other funding opportunities, offers only one type of funding.

The experience at both agencies converges when it comes to the general principle of decision-making for allocating funds to research; both follow a strict peer review procedure, which is the main reason for why, besides the obvious material (monetary) value, their funding also holds symbolic value (in the form of scientific reputation). For identifying interdisciplinary research, both agencies rely on negotiations, a communicative fabric of "collective tacit knowledge" (Collins 2010) between program officers, panelists, PIs, and others involved in the process of soliciting calls and conducting the review process. Nonetheless, different organizational provisions again leave their mark on when and where those negotiations take place. In the case of the NSF, those negotiations take place already when solicitations are developed and tailored funding streams dedicated to interdisciplinary research are set up; in the case of the ERC, they are restricted to the phase of reviewing.

Once potentially interdisciplinary research is submitted to regular programs of the NSF, their status is usually negotiated across programs, either because the PI requested a review by more than one program, or because a program officer considering a proposal thinks it is interdisciplinary and asks other programs to consider it as well. However, individual programs may feel beholden to the research communities they support, which makes them reluctant to do a lot of co-funding. Lacking the same organizational diversification, the ERC requires its panels to take over negotiations; the panels are composed to encompass several disciplines and, thus, are probably broader on average than their counterparts at the NSF. The risk, here, is that, while interdisciplinary proposals who (by chance) fall into the remit of a single panel are treated equally, those who cross the boundaries of two or more panels fare worse on average, probably because none of the involved panels takes full responsibility for them.

What does this mean for the way interdisciplinary research is problematized and defined at "boundary organizations" such as funding agencies more generally? There can be no doubt that funding interdisciplinary research has become a crucial aspect even of traditional funders aiming at fostering academic research. However, what is perceived as being "interdisciplinary" (as in contrast to disciplinary) research depends on the organizational structure of the funding agency itself.

To that end, the two case studies presented here also represent two different models, which can be found in various modifications across the globe. The NSF represents the classical, organizationally independent agency model. Operational flexibility and the range of options for implementing funding instruments enable the funder to dedicate funds specifically for promoting interdisciplinary research projects. Those come in addition to the funded research proposals that can be declared interdisciplinary as a result of a process of negotiations between programs. Promoting and identifying interdisciplinarity is explicitly subject to the processes of tailoring adequate funding opportunities and selecting proposals for funding. Interdisciplinarity gains an exemplary status that can be continuously highlighted and promoted; inevitably, however, this goes along with the admission that, at least some of the overall funding is still allocated to regular, that is, noninterdisciplinary, research.

The ERC represents more of a hybrid model to the extent that it claims some aspects of organizational independence, but really is part of a larger bureaucratic structure in which it sits as one (though very distinct) program among many. The ERC does not have available the same set of instruments; and since negotiations take place across panels within the same funding stream, the funded cross-panel proposals usually do not carry the same cogency. Instead, the funder claims that all its funded projects are somewhat interdisciplinary, since panels comprising experts from several disciplines scrutinize them all. That approach appears to be innovative and also more in line with the general emphasis for postacademic, or "Mode 2" research configurations, if only because it suggests that interdisciplinary research is fully integrated and taken care of by the funder. However, it is difficult to actually "prove" this implicit assumption, and the sobering conclusion is not too far-fetched that, at the end of the day, most funded projects remain firmly in a disciplinary framework.

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Toward a New Discipline of Integration and Implementation Sciences

GABRIELE BAMMER

One of the challenges of interdisciplinary research is the range of practices covered by the term, including:

- research at the intersection of two disciplines, such as biology and chemistry or psychology and mathematics, resulting in the formation of new disciplines (biochemistry and mathematical psychology); a process that can be large- or small-scale and undertaken by individuals or teams;
- research across boundaries of several closely related disciplines such as sociology, anthropology, and psychology, involving extensive "borrowing" (Klein 1990) of concepts and methods; a process that can also be large- or small-scale and undertaken by individuals or teams;
- fields and "disciplines," such as women's studies, population health, criminology, and media studies, that draw on a range of disciplinary inputs; a process in which different disciplines may work together closely or operate in parallel;
- research on phenomena that occur across different disciplines, such as patterning or hierarchy—for example, patterns occurring in the natural world and in social systems from chemical structures at the microscopic level, arrays of stars, planets, and other objects in the astronomical world to movements of fish and birds, friendship networks, and traffic flows (Drexler 2010);
- research that involves experts from various disciplines and stakeholders from relevant practice areas working on a common complex problem, such as cybercrime, obesity or soil erosion, a process that develops not only improved understanding but also supports action on the problem.

Of particular interest here is the last of these practices, a style of research that can be named "integrative applied research." In an earlier work (Bammer 2013), I outlined the benefits of establishing a discipline to underpin integrative applied research, and proposed the name integration and implementation sciences (I2S). Integration and implementation sciences has three core domains, illustrated in Figure 36.1. This discipline would act as a repository for concepts, methods, and case examples for:

1. Bringing together knowledge from different disciplines and stakeholders, who are those affected by a problem under investigation and those in a position to act on it. Stakeholders may include community groups or workers in particular occupations and policy makers, business entrepreneurs, or occupational professionals such as doctors or farmers.
2. Understanding and managing diverse unknowns. Given that not all unknowns can be eliminated, effective ways of dealing with those that remain are required when taking action on a problem. This strategy is particularly important for minimizing adverse unintended consequences and unpleasant surprises.
3. Providing integrated research support, which takes into account both what is known and what is not known for action, whether through policy or practice.

(*cont.*)

Bammer, G., *Sidebar: Toward a New Discipline of Integration and Implementation Sciences.* In: *The Oxford Handbook of Interdisciplinarity, Second Edition.* Edited by Robert Frodeman, Julie Thompson Klein, and Roberto C. S. Pacheco: Oxford University Press (2017). © Oxford University Press. DOI 10.1093/oxfordhb/9780198733522.013.42

Toward a New Discipline of Integration and Implementation Sciences (cont.)

A five-question framework assists the repository function of the I2S discipline, especially cataloging and retrieving relevant practices:

1. What is the integrative applied research aiming to achieve, and who is intended to benefit?
2. What knowledge is synthesized, unknowns considered, and aspects of policy and practice targeted in the integrative applied research?
3. How is the integrative applied research undertaken (the knowledge synthesized, diverse unknowns understood and managed, and integrated research support provided), by whom, and when?
4. What circumstances might influence the integrative applied research?
5. What is the result of the integrative applied research?

Let us now consider these questions in more detail.

Question 1—For what and for whom?—may seem banal, but the purposes of research are often poorly thought through. As a consequence, suboptimal practices may be used to address the other four questions.

Question 2—Which knowledge, unknowns, and aspects of policy and practice?—covers concepts, methods, and cases for:

- dealing with both the problem and the domain in which action will be supported as interconnections between systems;
- scoping effectively what different disciplines and areas of practice have to offer in terms of relevant knowledge and unknowns, as well as domains in which action could be supported;
- establishing boundaries, based on the scoping, to determine what will be included and excluded in the research process and where support for action will be targeted;

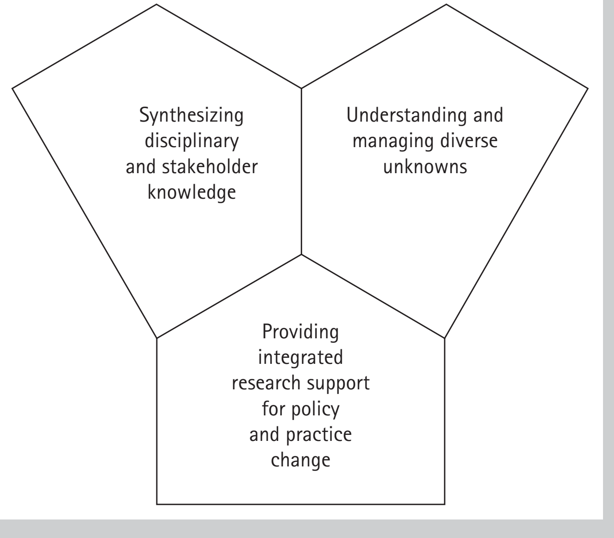

FIGURE 36.1 Three core domains of integration and implementation sciences (I2S).

- framing both the problem and research findings to aid communication and action;
- identifying the values at play, along with managing any value conflicts that arise during research or implementation of findings;
- harnessing and managing differences, which is the essence of collaboration for both research and action. The aim is to harness the differences that provide the rationale for the collaboration and to manage those that are sources of irritation and impede collaboration.

Question 3—How?—deals with methods for knowledge synthesis, understanding, and managing unknowns, and providing integrated research support for policy and practice change. Methods for knowledge synthesis can be thought of in three classes, those based on:

1. dialogue, for example, citizens' jury and nominal group technique (McDonald et al. 2009);
2. building something together, whether a conceptual or mathematical model, product (e.g., constructing the atomic bomb; Rhodes 1986), or vision (e.g., the role of dams in society; World Commission on Dams 2000);
3. common metrics, for example, dollar value or disability-adjusted life years (DALY; Murray et al. 2000).

When it comes to unknowns, the most common methods are reduction and banishment, in other words converting the unknown into knowledge or ruling it out of scope. When dealing with complex problems, other methods must also be brought to bear, most importantly acceptance that the unknown exists, cannot be reduced, and should not be banished. Relevant methods include employing the precautionary principle (United Nations Conference on Environment and Development 1992), developing scenarios (Badham 2010), and using methods from economics such as diversification and hedging.

Finally, three common methods provide research support for policy and practice change:

- informing policy makers and practitioners about research findings through various forms of communication;
- advocating for particular types of change based on research findings;
- engaging with policy makers and practitioners to develop shared understanding of a problem and a joint strategy for action.

Question 4—Context?—examines the circumstances in which integrative applied research occurs, especially those that can affect understandings and action. Context can be usefully considered to have three key elements: overall context, authorization, and organizational facilitators and barriers. Overall context refers to the big picture in which integrative applied research occurs such as the history of the problem and action taken on it, influences from geography and culture, and political possibilities for intervening in a problem.

Authorization looks at sources of legitimacy for research and action. For most research, funding is the only source of authorization required, but in some instances further authorization is established by, for example, setting up an Advisory Committee or even seeking permission from political leaders (for instance, the atomic bomb project needed authorization from the US president; Rhodes, 1986). The important point is that authorization comes with a cost. For example, funding determines which research is conducted, and committees or others providing legitimacy may restrict how research is undertaken or what action is proposed.

(*cont.*)

Toward a New Discipline of Integration and Implementation Sciences (cont.)

Finally the structure and culture of organizations undertaking research, as well as of stakeholder partners, will facilitate some aspects of integrative applied research and provide barriers to others. A limited disciplinary mix in a participating organization will hinder cross-disciplinary collaboration or, conversely, the culture of mixing freely in a shared lunchroom may facilitate exchange of ideas.

Question 5—Outcomes?—uses the other four questions as the basis for evaluating integrative applied research, asking for example:

- Were aims and beneficiaries clearly articulated for each of the three domains?
- Was an effective systems analysis used as part of knowledge synthesis?
- Were effective methods used for managing unknowns?
- Were lessons from previous attempts to offer research support for policy action on the problem understood and taken into account?

Of course, providing a repository of concepts, methods, and case examples is only one function of a discipline. How else can a discipline of I2S assist integrative applied research? Statistics offers useful lessons, especially because it primarily provides concepts, methods, and case examples for advancing research on a wide range of problems (in this case quantitative analysis). In statistics, disciplinary advances are also largely based on lessons learned from working on concrete problems. Likewise, I2S would advance by incorporating practice insights gained by teams working on complex real-world problems. The discipline of statistics delivers a conduit, allowing statisticians working on problems in, say, education to pick up methods innovations made by those working in, say, health. Thus, I2S would provide an analogous conduit between, for example, teams working on complex environmental problems and those working on complex security problems.

Another parallel with statistics lies in the way expertise is distributed throughout the statistics research community. It is useful to think of three different classes of researchers, each with its own level of expertise: (1) a small core who develop the theoretical basis for the discipline, primarily but not exclusively, using mathematical principles; (2) the bulk of statisticians, who develop theoretical and methods insights by engaging with real-world problems, usually as part of a research team; and (3) the bulk of researchers in quantitative fields, who generally have enough appreciation of statistics to be able to do some procedures themselves and bring in statistical collaborators when more advanced methods are needed. Similarly, one can envisage three levels of expertise in I2S: a small core who continue to build the theory of the discipline; the bulk of I2S specialists who advance the discipline's methods and concepts as members of teams working on complex real-world problems, and the majority of team members working on complex real-world problems who have some understanding of I2S concepts and methods but rely on an I2S specialist on the team for more detailed and developed expertise. For example, one team member may have the experience necessary to lead building an integrative model, but rely on the I2S specialist to run the contributing dialogue-based processes and to chart a way forward in implementation of the model's findings.

Capacity building is the final parallel with statistics. Just as there are pathways for students to specialize in statistics, there would be analogous pathways for specializing in I2S. Further, just as many researchers have been exposed to statistics as part of their education, most researchers who contribute to understanding and acting on complex real-world problems need to be exposed to the basics of I2S as part of their education. In the case of both statistics and I2S, this capacity allows the bulk of researchers to interact more effectively with statistical or I2S specialists.

Developing a new discipline obviously needs to be a joint exercise by those who would be its members. There is much work to do in continuing to progress the underpinning intellectual basis—by gathering and making available existing I2S methods and concepts, demonstrating successful applications, and learning lessons from applications that have failed. Practical and political work is also needed, including building a college of peers who have relevant experience to review grant applications and papers submitted for publication, developing appropriate journals, and building workable institutional arrangements.

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CHAPTER 37

ADMINISTERING INTERDISCIPLINARY PROGRAMS

KARRI HOLLEY

The academic structure of colleges and universities influences and directs the ability of contemporary higher education to fulfill the mission of knowledge production. Significant aspects of the twenty-first-century environment shape the administration of interdisciplinary programs. In all but the wealthiest institutions, administrators and faculty face unpredictable revenue sources and enhanced pressures toward measurable outcomes such as graduation and employment rates (Altbach et al. 2011). For public institutions, weakened state funding levels provide less support for institutional functions and in many cases, more restrictions on institutional behavior. The development of alternative curriculum formats such as MOOCs and competency-based learning alters the ways that academic institutions and their faculty interact with students. While the demographics of postsecondary students grow more diverse, the percentage of tenured or tenure-track faculty grows smaller. The demands to produce job-ready graduates, or those with skills that can immediately contribute to the workforce, deafen the interest in traditional liberal arts values, such as critical thinking and multicultural understanding (Newman et al. 2010). Since students and their parents pay a greater percentage of tuition than ever before, many graduates seek an immediate return on their investment as they move into their professional careers. This challenging environment for higher education shifts the way that knowledge is conceptualized, packaged, and accessed. This shift (and the accompanying demands) impacts the administration of interdisciplinary programs.

This chapter considers the administration of interdisciplinary programs within this volatile context. Federal government agencies, private foundations, for-profit industry, and the general public all call for colleges and universities to produce knowledge of relevance unconstrained by disciplinary boundaries (Altbach et al. 2011). Facilitating interdisciplinary work among faculty, researchers, and students enables higher education institutions to respond to these demands.

The lengthy history of interdisciplinary activity in higher education offers important lessons about developing, administering, and assessing interdisciplinary programs. A deepening body of literature surrounding higher education studies and organizational theory

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surrounds these lessons. This literature acknowledges that, like any other system, higher education institutions face multiple influences from both internal and external stakeholders. This interaction requires an understanding of the environment in which higher education institutions operate.

On one hand, interdisciplinary programs contribute to the sort of innovation and responsiveness demanded of higher education institutions. Recent reports from the National Academies of Science, Engineering, and Medicine on convergence and team science illustrate how higher education institutions "facilitate the transfer of knowledge, ideas, and technology to society and accelerate 'time to innovation' in order to achieve our national goals" (NRC 2012, p. 11). Interdisciplinary programs frequently evolve around emergent topics or issues that hold great promise for social, cultural, and economic advancement. They exhibit more flexibility compared with traditional academic departments, allowing for experimentation related to pedagogy, content, and outcomes (Casey 2010). On the other hand, interdisciplinary programs represent a risky undertaking for colleges and universities. In times of organizational upheaval, institutions commonly turn to enhanced control and standardization as a way to facilitate desired outcomes. The difficulty of assessing the outcomes of interdisciplinary work using measures developed for traditional disciplinary undertakings remains. Colleges and universities face obstacles in developing ways to administer interdisciplinary programs that are financially viable and culturally sustainable.

This chapter begins from the position of a changing environment for higher education to consider the challenges associated with administering interdisciplinary programs. After establishing organizational norms unique to higher education institutions, the chapter considers three specific areas: (1) the role of boundaries in shaping the university, and how interdisciplinary programs negotiate these boundaries; (2) the persistence of disciplinary cultures, and their impact on interdisciplinary programs; and (3) the resource challenge for contemporary higher education, and how this debate affects interdisciplinary activities.

37.1 Organizational Norms Unique to Higher Education Institutions

Higher education institutions exhibit unique organizational characteristics that enable them to fulfill multiple, ill-defined, overlapping, and sometimes conflicting goals (Clark 1986). Durkheim described colleges and universities thus: "It is rare to find an institution which is at once so uniform and so diverse; it is recognizable in all the guises which it takes, but in no place is it identical with what is in any other" (1977, p. 75).

This section briefly introduces three norms of higher education institutions that both facilitate and constrain efforts toward interdisciplinarity. First, disciplinary groupings (including academic departments and colleges) typically define colleges and universities. These groups exhibit a physical footprint on campus with buildings and corridors dedicated to study in a specific area. Yet the distinctions go beyond physical boundaries. Scholars from arts and sciences, engineering, business, education, and so on neatly divide campus culture. These scholars progress through doctoral programs that provide them with disciplinary expertise, and then practice their work in disciplinary silos.

The curriculum details further evidence of the territorial nature of the academic disciplines. The institutional catalog distributes topics of study and fields of knowledge among the colleges and departments. Advantages exist with this structure. Specialized bodies of knowledge develop from the interaction of experts, allowing for the depth of knowledge inherent to advanced study. Different generations of scholars pass down these bodies of knowledge, offering continuity in epistemological developments (Becher & Trowler 2001). Yet this structure restricts potential conversation, collaboration, and discovery among *different* bodies of knowledge. Even though knowledge cannot be contained solely within disciplinary boundaries, the structure of higher education restricts conversations with scholars from different fields (Clark 1986). In addition, the organizational tendency of higher education institutions toward loosely coupled structures works to shape academic cultures. Loosely coupled systems demonstrate weak, occasional, or indirect connections between various units (Orton & Weick 1990). Loosely coupled units do not rely on the behavior of other units to survive. Each unit perceives and responds to environmental situations in ways that provide the opportunity for success. This structure also enhances opportunities for innovation, since individual units may engage in risky or experimental actions that are not likely to damage organizational well-being. In the same ways that disciplinary cultures distance academics from each other, a loosely coupled organization greatly challenges efforts toward coordination and standardization (Orton & Weick 1990). Since units do not need each other to survive, the motivation for shared and collaborative behavior declines. An innovative success in one unit is not likely to spread to another. Similar efforts can be unnecessarily duplicated across the institution, and a decision to coordinate institutional activity can be costly, frustrating, and ultimately not successful. By design, the organization exists in a manner that allows programs to act independently in ways that fulfill their unique mission.

A third unique characteristic of higher education institutions is that of a professional bureaucracy. Mintzberg defined the professional bureaucracy as one that "relies on the standardization of skills in its operating core for coordination; jobs are highly specialized . . . [and] grouping is on a concurrent functional and market basis" (1980, p. 322). Perhaps nowhere else in higher education is the professional bureaucracy more evident than in the faculty. While some standardization exists among faculty (for example, most faculty at 4-year research institutions are required to hold a PhD or other terminal degree in their field), expertise is content-specific. Faculty practice their skills through the functional grouping of the academic department, and this context gives their skills meaning (Mintzberg 1980). All faculty may be expected to teach an entry-level lecture course at some point over their career. How such a course is designed and implemented in biology as opposed to English, for example, reveals much about the nature of professional expertise.

Traditionally, in organizational behavior, the more skilled the job, the less likely it is to be formalized; the work of experts in one field cannot be assessed by the same measures as the work of experts in another (Collins & Evans 2008). Administrators hold minimal influence over the work of faculty, as evidenced by the vertical and horizontal decentralization of the organizational structure. The assessment of disciplinary, departmental, and college peers shapes tenure decisions, one of the primary means by which an institution invests in the long-term work of its faculty. As a result, faculty likely feel a closer connection between individuals within their same discipline or field of study than they do with others on their same campus; their allegiance to disciplinary norms overshadows their investment in institutional behavior, and they may be unwilling or unable to shed these disciplinary ties for more broadly encompassing institutional initiatives.

When examined cumulatively, these three organizational characteristics strongly impact the administration of interdisciplinary programs. Not only must faculty from different fields of study be brought together in conversation but also they must do so in a language that can be understood across disciplines. Interdisciplinary programs require individuals to step out of the loosely coupled nature of the university (i.e., the department) and into a shared space that allows for collaboration. The shared space requires coordination from some institutional authority outside of the typical departmental unit. Faculty must be motivated to sacrifice some extent of disciplinary autonomy, both related to knowledge production as well as institutional structure (Lattuca 2001). The administration of interdisciplinary programs requires not just tackling the epistemological certainty and foundation that resides within the academic discipline but also designing unique organizational structures to facilitate this work.

Globally, higher education institutions face obstacles related to productivity, efficiency, and relevance. The institutional contribution to the economic and social well-being of the nation-state features prominently in the international portrait of higher education (Altbach 2008). The organizational context and logic in which interdisciplinary programs reside undermines their efforts toward productivity and efficiency.

37.2 How Interdisciplinary Programs Negotiate Institutional Boundaries

Historically, literature related to the administration of interdisciplinary programs assumes the problematic presence of institutional boundaries, which serves as the frequent starting point for conversations. How can faculty, students, and knowledge be brought out of the disciplinary context into an interdisciplinary discussion? For programs to be successful, they must negotiate across disciplinary, departmental, and college boundaries. While this statement is true, it obscures the complex and multiple ways in which interdisciplinary activity occurs. No single model for an interdisciplinary program exists. Interdisciplinary programs can be completely autonomous and independently housed within the college or university, or they can be represented by an informal collaboration among small groups of faculty. Some interdisciplinary programs arise from grassroots efforts by committed faculty or students. Others originate from large-scale external research grants designed to foster innovative curricula or research outcomes (Sa 2008).

The involvement of external stakeholders in fostering interdisciplinary activity in multiple national contexts illustrates different influences: In the United States, the University without Walls program originated in 1971 with investment from the then-Department of Health, Education, and Welfare and the Ford Foundation to develop external bachelor's degree programs that crossed traditional disciplines (Koontz 1972). In Brazil, the 2006 federally supported Program for the Re-Structuring and Expansion of Federal Universities prioritized socially responsive, flexible, and at times interdisciplinary undergraduate curricula (Mancebo et al. 2015). In Russia, the Skolkovo Institute of Science and Technology (known as Skoltech) will receive $15 billion in state and private funding to develop interdisciplinary research programs by 2020 (Kinossian & Morgan 2014). Despite the variation in approaches, interdisciplinary efforts share the need to develop physical and organizational space within the institutional structure in order to accomplish their goals.

The construction of physical spaces to further interdisciplinary work occurs at some institutions. American colleges and universities have seen a marked increase in the number of buildings devoted to interdisciplinarity over the last decade, particularly in science, technology, engineering, and mathematics (STEM) areas. Stanford University's Yang and Yamazaki Environment and Energy Building (Y2E2) facilitates conversations among researchers interested in environmental science. The building houses faculty, research centers, and program affiliates in one building; previously, these groups were scattered across the campus, making the very act of conversation, much less collaboration, difficult. Multiple thematic groups work in Y2E2, and color-coded walls indicate which groups are housed where. The visual power of a new building serves to facilitate the administration of the interdisciplinary program, and visual indication of specific research foci reinforces the collaborative nature of the work (Stanford Report 2008). As another example, Penn State University built a new Life Sciences Building in 2004. The complex actually consists of two buildings, one devoted to chemistry, the other to biology. A glass-enclosed walkway that enables easy access by faculty and students joins the buildings, which serve as the home to the interdisciplinary Huck Institutes of the Life Sciences. The symbol of the glass-enclosed walkway provides a literal image of interdisciplinary collaboration (Fagone, 2003).

Not all interdisciplinary programs are housed in newly constructed buildings. The renovation of existing space to house interdisciplinary efforts serves as a powerful cultural symbol of an institution's commitment to such work. Wellesley College's master plan prioritizes renovation of existing structures to provide "flexibility for new disciplines and pedagogies, while encouraging and supporting collaboration and enhancing sustainability" (Wellesley College 2013). The 2013 master plan for Antioch College features similar rhetoric. Antioch's science building will be renovated to include space for the arts, enabling the college to "model the true meaning of integrated, interdisciplinary instruction at the heart of campus" (Antioch College 2013). Interdisciplinary programs also flourish in virtual, online spaces. The University of Southern California's Institute for Creative Technologies features multidisciplinary virtual interactive technologies where students spend part of their time online interacting with peers, faculty, and industry stakeholders (USC 2014). On a very basic level, fostering interdisciplinary collaboration requires fostering interaction between individuals who might not otherwise be in close proximity.

The administration of interdisciplinary programs also requires attention to organizational space. Numerous models and approaches to organization can be seen when examining the landscape of interdisciplinary efforts. One approach is a freestanding unit, reporting directly to the central administration. The University of Minnesota's interdisciplinary graduate program in conservation biology is directed by two faculty members, the director of graduate studies, and the director of graduate admissions. Governance occurs through three standing committees, and faculty rotate program responsibilities with those from their home department. Another model is located within academic colleges, or, less frequently, departments. The University of Alabama's New College was founded as an interdisciplinary, independent undergraduate degree program in 1971. Some 30 years later, New College was moved under the administrative oversight of the College of Arts and Sciences; the director of New College reports to the dean of the College.

How interdisciplinary programs are organized offers insight into the supporting funding and governance mechanisms (Klein 2010). Programs outside a departmental or college structure can originate with a start-up investment with expectations of future self-sufficiency, or may rely on funding from the central administration indefinitely. The lack of a proprietary funding source could provide challenges for freestanding interdisciplinary programs. The last two decades witnessed the growth of incentives-based budget systems (IBBS), which transfer budgeting decisions to the individual unit, but also require greater accountability and self-reliance from these units (Hearn, et al., 2006). In these systems, also referred to as revenue- or responsibility-centered management, tuition revenue flows proportionally to the unit from which it originated, as do costs associated with unit activities.

Interdisciplinary programs experience vulnerabilities regardless of the funding mechanism. If freestanding units are funded directly through the central administration and the institution's general fund, they become reliant on the willingness of administrators to value the unit's future work. However, if freestanding units are self-funded, they must rely on student tuition, state appropriations (in public institutions), and grants for survival. Student enrollment is the measure by which the program is evaluated; a program with low student enrollment or low graduation rates faces vulnerability in times of fiscal uncertainty. The relentless emphasis on productivity challenges both traditional and interdisciplinary programs. Conversely, interdisciplinary programs housed within traditional colleges might not face the same financial pressures on productivity as a means of survival, but might experience constraints related to governance and decision-making that is located within a specific group of disciplinary perspectives.

37.3 The Impact of the Academic Disciplines on Interdisciplinary Programs

A wealth of existing literature considers what role the academic disciplines play in shaping interdisciplinary processes and outcomes, an appropriate question given the historical development of higher education. The development of academic departments in the late 1800s, combined with the solidification of a core undergraduate curriculum in the early 1900s, left little room for academic engagement outside of these organizational norms (Rudolph 1962). Understanding the administration of interdisciplinary programs requires not only understanding the barriers to such efforts but also the ways in which different disciplines can be integrated under a sole programmatic umbrella.

Consider, for example, interdisciplinary undergraduate degree programs, which exist at numerous academic institutions. One type of program caters toward nontraditional and adult students who may be attending college later in life. These students might bring in competency-based credits, or perhaps have earned academic credit from other institutions. These interdisciplinary programs develop a post facto foundation under previous disparate academic experiences. The School of Continuing and Professional Studies at the University of Virginia "makes it possible for working adults to complete a degree from the [university] in the evenings, on a part-time basis" through its interdisciplinary studies undergraduate degree program. Students bring with them 60 credit hours earned at other institutions that must satisfy the UVA liberal arts core. The UVA requires 60 hours to be earned in the interdisciplinary studies program to be completed as either a business or liberal arts concentration. The bulk of the coursework is completed with faculty outside of the School (UVA 2015).

A second approach toward interdisciplinary undergraduate degrees is a "design your own" program, where interdisciplinarity is an a priori motivation and where students bring a unique interest to the institution that cannot be accommodated by a traditional academic unit. Often such programs tout freedom from a prescribed curriculum or the ability for students to experiment with different epistemological content, although questions remain about whether such programs offer an interdisciplinary learning experience. These programs can be freestanding, part of a larger department or College, or in rare cases, reflective of the entire institution. Evergreen State College, as an example, holds interdisciplinary tenets at the core of its undergraduate curriculum, and supports student and faculty learning across traditional disciplinary boundaries.

Typically seen on a smaller organizational scale, interdisciplinary degree programs became common in the experimental decades of the 1960s and 1970s. Higher education institutions frequently support both types of interdisciplinary programs. The University of Minnesota's College of Continuing Education offers both an "inter-college" and a "multidisciplinary studies" degree. The former is targeted toward students with interests in more than one discipline who seek individualized learning opportunities. These interdisciplinary thematic programs of study concentrate on a single theme or problem. The multidisciplinary studies degree is advertised for students who have already completed college courses, but do not have enough credits for a degree. While the two degrees exist within the same academic college, their differences emphasize important distinctions related to interdisciplinary programs. The inter-college degree evolved from UM's University College, which originated in 1930 in an effort to facilitate diverse student interests that encompassed multiple fields of study. University College became the Inter-College Program in 1969, and experimented with different kinds of learning communities, curriculum, and social justice emphases. The Inter-College Program merged with the UM College of Continuing Studies in 1996. The multidisciplinary studies degree is a new addition to the College. Unlike the inter-college program, which focuses primarily on traditional students, the multidisciplinary studies program targets working adults with a gap in their educational history. Similar efforts exist at other institutions, including the University of Alabama's New College (including a residential interdisciplinary undergraduate degree for traditional students and a "LifeTrack" format, which targets nontraditional students with distance learning options) and the University of Wisconsin-Green Bay (including a residential integrated leadership studies degree for traditional students and a bachelor of applied studies degree, designed for nontraditional students with previously earned credits).

The evolution of UM's Inter-College illustrates how the same program may change organizational structure over time in response to both internal and external demands. The Inter-College Program of the 1970s privileged the experimental (but not necessarily cost-efficient) approach to education common during the decade. However, by the 1990s, the university embraced the concept of revenue-centered management across the campus. The Inter-College Program merged with the short-lived University College, and then the College of Continuing Studies, as a way to achieve the goals associated with the University 2000 strategic plan. Inter-College, along with other units, "radically restructured its finances, programs, internal and external relationships, organizational structure, and staffing levels" to offer financially viable programs of study (Norman 2006, p. 74).

Another distinct type of interdisciplinary program focuses on niche knowledge areas, such as gender studies, environmental studies, race/ethnic studies, and human ecology. Each field represents unique influences in terms of its development. The first women's studies program began in 1969 during an era of increased emphasis on women's experiences, while human ecology gradually evolved from developments in sociology, anthropology, and human economics that resulted in the birth of a new field of study. These types of programs are most frequently found within academic colleges; their interdisciplinary origins are more difficult to assess from a structural or administrative viewpoint, even as their popularity has grown tremendously in recent decades (Brint et al., 2009). In part, this challenge is due to the increase in the number of PhDs being awarded in these areas. Rather than hiring faculty from constituent disciplines, niche interdisciplinary areas can now find more faculty with a PhD in the specific field. Emory University offered the first American PhD in women's studies in 1990. Some 20 years later, 16 institutions offer the doctorate (Reynolds et al. 2007), and a growing number of faculty in women's studies programs possess a PhD in the field. Other disciplinary hallmarks such as field-specific peer-reviewed journals and field-specific scholarly associations blur the interdisciplinary nature of niche knowledge areas. As these areas exhibit more and more disciplinary characteristics, it becomes difficult to characterize and manage them as constituting an interdisciplinary field, as they move toward their own disciplinary status.

These different approaches toward interdisciplinary outcomes exhibit consequences for faculty hiring, curriculum development, and organizational structure. The institutional power of academic programs that hire their own faculty, for example, should be considered. These programs invest in their epistemological futures by making strategic hires based on perceived need. Ideally, although certainly not always, disciplinary programs develop a shared consensus reflected in a program of study required for student learning. When interdisciplinary programs send students to other academic departments and colleges, the responsibility to provide an integrative foundation is increased. Students may acquire their interdisciplinary education piecemeal, through an assortment of courses that may not have any visible links to another. One result is the evidence of capstone projects and regular interdisciplinary-focused seminars as a way to make the assortment of coursework more cohesive. On the one hand, interdisciplinary initiatives demand freedom from traditional disciplinary confines and the ability to pursue innovative outcomes. On the other hand, these initiatives depend on the college or university for support, and rely on the disciplinary contributions (i.e., faculty, knowledge, etc.) for inputs in order to achieve interdisciplinary outputs.

37.4 Resource Challenges and the Administration of Interdisciplinary Programs

The ability of interdisciplinary programs to generate revenue that sustains their work is challenged by the organizational structure through which they operate. Often such programs are strong candidates for initial institutional investment with the expectation of future funding from other sources. Programs may survive based on student tuition dollars, or be supported as institutional evidence of innovation. Uncertainty regarding financial resources can place interdisciplinary programs in a vulnerable position, particularly compared to more traditional departments or those through which a large percentage of the undergraduate student population is required to pass (i.e., English, mathematics, and sciences). "When systems are stressed (for example, by financial or resource constraints), they tend to revert to their old, familiar, and traditional ways of operating," concluded Clark (2004, p. 257). "When the supply of money is limited in higher education, the luxury of innovative, interdisciplinary courses or programs rapidly gives way to the necessity of covering the basic curriculum." One factor influencing the sustainability of courses or programs is where they are housed within the institution. If a group assumes some sort of responsibility for the initiative, then the chances for long-term success are higher. Typically such initiatives are found within organized research units (ORUs), interdisciplinary centers, or interdisciplinary colleges within the university. The viability of these interdisciplinary units, of course, is highly dependent on the central administration's favorable support.

A common approach toward resource generation related to interdisciplinary work is the procurement of external funding. For example, the biology department at Arizona State University relied on indirect funds generated through external grants focused on undergraduate and graduate programs. These grants supported curriculum development and pedagogical workshops for faculty (Collins 2002). In addition, over time, faculty worked with collaborative groups to receive multidisciplinary and interdisciplinary grants, further developing an interdisciplinary culture within the department. Faculty enhanced coursework by adding courses from liberal arts disciplines, an undergraduate interdisciplinary minor in biology and society, and undergraduate research opportunities; the university awarded funds to cultivate undergraduate research, which furthered interdisciplinary activity. The dean of the college of arts and sciences, where the department is housed, introduced new policies that offered flexibility in how teaching loads were assigned and ways in which faculty were rewarded for participating in interdisciplinary activities. The departmental and college initiatives were later matched with an institutional, aggressive, top-down endorsement of interdisciplinarity accompanied by a willingness to restructure the organization. A lesson from ASU's change is that institutional stakeholders must first recognize that change needs to occur, find the support (financial, personnel, and the like) to sustain the change, and match changes to institutional priorities and plans (Collins 2002).

Particularly over the last decade, STEM-focused interdisciplinary areas have seen abundant opportunities for external funding. The Interfaces in Science program at the University of California in San Diego provides interdisciplinary engagement in the spaces between the physical, medical, engineering, and biological sciences. Doctoral students admitted to a traditional PhD program at UCSD apply to Interfaces, where they study in laboratory-based courses taught by an interdisciplinary team of faculty. The program is one of numerous efforts around the United States jointly supported by the Howard Hughes Medical Institute and the National Institute on Biomedical Training and Bioengineering. The initial HHMI funds supported curricular innovation, while the NIBTB funds enabled institutionalization of innovative outcomes.

Other programs originate after external awards are made and opportunities develop for interdisciplinary engagement. The Institute for Interdisciplinary STEM Education originated at Georgia Southern University after two faculty groups received separate multimillion dollar National Science Foundation grants. Additional grants followed, and the Institute organized as an interdisciplinary unit reporting directly to the vice president for research and economic development. Eventually, the Institute plans to offer an interdisciplinary master's degree for science teachers. Serious concerns exist about the long-term sustainability of interdisciplinary programs after the initial investment by external groups or the institution itself. Faculty members may be constrained by the need to provide instruction in their home department. Faculty positions may be grant-dependent, requiring faculty to continually seek external grants as a way to maintain their position of employment (Clark 2004).

Another approach to cultivating interdisciplinary programs involves enhancing extant niche areas within an existing academic unit, or fostering a disciplinary-based interdisciplinary initiative. In doing so, interdisciplinary signatures become a marketing asset, allowing the institution to identify and prioritize their strengths in ways attractive to potential students. At the University of Colorado Denver, the College of Liberal Arts and Sciences developed seven interdisciplinary "signature areas," which united the disparate academic departments and enhanced the College's institutional and public profile. The signature areas were determined after a competitive proposal process open to all faculty within the College. The dean's office committed initial funding with the expectation that each area would seek external funding in the future to support their work (Stone et al. 2009).

As an example of topical interdisciplinarity, cluster faculty hiring initiatives have assumed an increasingly common role in developing interdisciplinary efforts on campus. The University of Wisconsin in Madison is among numerous universities to implement a faculty cluster-hiring initiative. In 1998, the university raised nearly $15 million in state and matching private funds (Sa 2008) to start the work of hiring 140 faculty to work in interdisciplinary clusters. While the faculty were housed in traditional academic departments, their salaries were funded by the central administration. Other universities have implemented the cluster or constellation hiring approach, where faculty with complementary areas of expertise are hired in groups—among them, the University of Southern California in 2002, University of Michigan in 2007, University of Iowa in 2010, and North Carolina State University in 2012.

A few institutions, such as the Massachusetts Institute for Technology, have prioritized faculty cluster hires over single-line faculty searches. These initiatives share several common elements, including the hiring of "star" researchers or those with expertise in a shared area. The rhetoric that underlines cluster faculty initiatives is indicative of the perceived relevance of interdisciplinary work. These programs emphasize areas of study that cut across the academic disciplines, or cannot be adequately contained in existing academic departments. In addition, these programs are prominently featured as an example of institutional commitment to interdisciplinarity, although concerns have been raised about the neglect of faculty hires in core disciplines (Holley 2009). It is noteworthy that cluster-hiring initiatives are most commonly coordinated at the level of the central administration, and not from the academic colleges.

Issues regarding faculty and interdisciplinary programs cannot be discussed without acknowledging the larger context surrounding the American professoriate. Seventy percent of American faculty are contingent, working either part-time or full-time positions off the tenure track (Kezar 2013). Contingent faculty typically teach large course loads with little participation in university service and no power or involvement in university decision-making. For interdisciplinary programs staffed by contingent faculty that rely on the administration's goodwill for their existence, these facts are troubling.

Table 37.1 A Typology of Interdisciplinary Programs

Elements	Variations
Students	Undergraduate, master's, or doctoral students Traditional-age or non-traditional-age students On campus, off campus, or hybrid students Full-time or part-time students Students enrolled full-time in other academic programs vs. full-time in the interdisciplinary program
Faculty	Full-time, part-time, contract, or adjunct faculty Tenured, tenure-track, or non-tenured/tenure-track faculty Faculty with PhDs in multiple disciplines vs. PhDs in the interdisciplinary field Faculty with full-time appointments in other academic programs vs. full-time in interdisciplinary program
Curriculum	Institutional or student structured Degree of integration among courses Role of capstone or culminating class Can students bring in credits earned from other institutions at other times? Role of the academic discipline or disciplines
Funding	Grant funded Tuition driven Funded by central administration Generates own revenue Short-term, soft funding Long-term funding commitment
Institutional Location	Within an academic department Within an academic college Within the institution, but not an academic department or college Virtual

A typology of interdisciplinary programs reveals that not all programs share the same mission, orientation, or goal, even though they may share an interdisciplinary label (Knight et al. 2013). These distinctions involve the manner in which knowledge is compartmentalized, defined, and delivered to students. Other variables include the faculty, the funding source, the institutional location, and the student demographic.

Table 37.1 summarizes the various elements that contribute to interdisciplinary programming. Faculty, administrators, or observers interested in understanding interdisciplinary programs need to consider how each of these elements shapes the program model. These elements should not be viewed as an either/or dichotomy, nor can they be assessed without understanding the larger institutional context in which they operate.

37.5 Conclusion

An overview of interdisciplinary programs suggests important lessons for administrators, faculty, and institutions interested in pursuing such work, especially considering the rapid growth in the number of interdisciplinary programs since the mid-1970s in such fields as women's studies, ethnic studies, biomedical science, and environmental studies. While interdisciplinary programs can be found at all institutional types, they are most common at wealthier institutions, or those with a large arts and sciences core (Brint et al. 2009). These indicators highlight the continued importance of financial resources and campus infrastructure to the development of interdisciplinary activity.

Most significantly, no single model exists for interdisciplinary programming. Programs generally reflect the institutional culture and context in unique and sometimes subtle ways. Often, a program may not have visible indicators of interdisciplinarity. Interdisciplinary programs can be housed in traditional academic units. Faculty can identify with an interdisciplinary program as well as another academic department. Students cycle in and out of interdisciplinary programs, frequently on their way to or from a traditional academic department. Also, where a program is situated strongly influences such factors as resource management, decentralized decision-making, and physical space. It is difficult to assume that all interdisciplinary programs require decentralized governance outside of the traditional organizational structure, given this diversity.

The programs do, however, require some degree of independence from the silo mindset that dominates contemporary higher education. Faculty need to be able to cross disciplinary boundaries in terms of their research and teaching. Depending on the nature of the hire, faculty need to find cognitive and physical homes in multiple academic departments. Decisions must be made about programs of study that do not follow traditional paths, but still adhere to solid educational principles as well as accreditation requirements. In addition to the structural variety inherent to interdisciplinarity in higher education, the program's overall goals and mission play a key role in determining how the work is accomplished. Distinct differences exist between programs that cater to adult, nontraditional undergraduate students with previously earned academic credits and those for first-time, traditional freshman students who live on campus. Faculty and administrators must address the idea of productivity related to interdisciplinary programs, which may have unique dimensions when compared to disciplinary efforts. In an era where productivity is closely tied to resource allocation, these questions may be difficult to answer.

The administration of traditional academic units, which are vital components of the higher education landscape, is certainly not a clear or easy process. Traditional programs face some of the same external demands outlined here. Yet the crucial need for interdisciplinary knowledge as a way to approach complex issues and produce innovative outcomes suggests enhanced organizational attention is needed to the administration of interdisciplinary initiatives. In particular, the ability for institutions to tie interdisciplinary programming to other campus initiatives, nurture dedicated funding sources, and develop campuswide policies that support collaboration increase the likelihood of successful programs.

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CHAPTER 38

INTERDISCIPLINARITY AND THE STUDENT VOICE

CARL GOMBRICH AND MICHAEL HOGAN

38.1 Introduction

This chapter offers an account of the student experience of interdisciplinarity at the undergraduate level, and connects this experience to theory and practice in the psychology of interdisciplinary education (IE). We find that the student voice substantiates the value of IE from a number of perspectives.

The "psychology of interdisciplinarity" is still a young field, especially with regard to the student experience of interdisciplinarity. Bromme (2000) analyzed the "psychology of cognitive interdisciplinarity" but his subjects were not students. Lattuca et al. (2004), as part of their "Research Agenda on Interdisciplinarity," ask, "What types of students experience the greatest success on interdisciplinary courses?" But Spelt et al. in their "Systematic Review" (2009) still report that in their "evaluation of scientific research into teaching and learning in interdisciplinary higher education" there were "zero publications that addressed mainly the student" (2009, p. 371). In a significant new work on interdisciplinarity and the curriculum, David Morrison (2015) likewise notes the paucity of research in this area. Morrison addresses both the issue of psychological traits and expertise in the context of interdisciplinary learning, but among other gaps notes that there is "little in the . . . literature on the possibility of expertise in meta-cognitive skills" (2015, p.124).

What we might call the "interdisciplinarity in education" literature contains numerous references to such themes as "perspectives," "creativity" and the teaching of teamwork and twenty-first-century skills (Boix Mansilla 2010, Kings College London 2010). However, these have rarely, if at all, been explored in the context of the psychology of interdisciplinarity and the student experience. This chapter can therefore be seen as an exploratory contribution to this area of research, although, as will become apparent, further research is needed to test the qualitative data presented here.

The focus of this chapter is extended qualitative feedback from a sample of students ($N = 13$) on University College London's innovative interdisciplinary Arts and Sciences BASc (bachelor of arts and sciences) degree. In analyzing the data, connections are made with existing literature on personality traits and dispositions, metacognition and team-working.

Gombrich, C. and Hogan, M., *Interdisciplinarity and the Student Voice.* In: *The Oxford Handbook of Interdisciplinarity, Second Edition.* Edited by Robert Frodeman, Julie Thompson Klein, and Roberto C. S. Pacheco: Oxford University Press (2017). DOI 10.1093/oxfordhb/9780198733522.013.44

Although contested as measurable outcomes for education, the attributes of "openness," "creativity," "perspective-taking" and "bridging," as well as abilities in metacognition and team-working, are often referred to as forming part of the set of "twenty-first-century skills" and cited as important qualities for contemporary graduates. Our analysis substantiates the connection between IE and these qualities and may be helpful in evolving a vocabulary and conceptual framework to support the establishing of new interdisciplinary programs.

Unlike in the United States, interdisciplinarity is a relatively new concept in UK higher education (HE). In an era of the "global graduate," a better understanding of the student experience in the UK may therefore be helpful in other cultural contexts such as India and China, where interdisciplinary learning is not the historic norm but is now fast developing.

38.2 Background and Context of Research

It is notoriously difficult to define what we mean by IE. Perhaps the most useful definition is simply "any education that does not confine itself to studying just one of the existing academic disciplines." This may appear hopelessly broad, but in the context of the UK and other HE systems in which specialization at undergraduate level is standard, it has the virtue of excluding a great number of existing degrees. Under such a broad definition, a large array of curricula may lay claim to being interdisciplinary; but the BASc at University College London (UCL) is arguably the first major initiative in interdisciplinary undergraduate education in the UK this century. It began in 2012 with an initial intake of 87 students, which was probably the largest launch of a single undergraduate degree in UCL's history.[1] From September 2016 it will be over 450 students in steady state.

The BASc was the brainchild of Professor Sir Malcolm Grant (former president and provost of UCL) and Professor Michael Worton, vice-provost international and Fielding Professor of French. Its development was a central part of "Transforming Education," in the Provost's White Paper 2010–11 (UCL 2011). One of the authors of this chapter, Carl Gombrich, was appointed to the post of program director in October 2010 to lead the set-up of the program over 2 years and then its inauguration in 2012.

The first cohort of 41 BASc students[2] graduated in summer 2015. The degree classifications were 14 first-class honors, 26 upper second-class honors, and one lower second-class honors.[3] Recent graduates are progressing to a wide range of postgraduate programs—including a PhD in computational neuroscience, and master's degrees in paleobiology, energy systems, international security, urban design, law, English literature, and business—and to a range of jobs, including finance, consulting, law, NGO work, journalism, and so forth.

As mentioned, the concept of a broader or more interdisciplinary undergraduate education is historically alien to the UK. Most students take "single" or "joint" honors degrees. There are some noteworthy exceptions: For example, the famous degree of philosophy,

1 Personal e-mail from Professor John North.

2 This is roughly half the number who entered in 2012, as half that cohort have gone abroad for a third year of study in another country.

3 In terms of percentages of classifications, this is very similar to the honors output of other UCL degrees.

politics, and economics at Oxford. Scottish universities, too, have a tradition of greater breadth. But this is the land of the two cultures, after all, and crossing the divide between "arts" and "sciences" has been positively discouraged in some circles. This is in contrast to the United States, where the liberal arts tradition forms a helpful backdrop to discussions of interdisciplinarity. At a more global scale it is notable that the discussion of interdisciplinarity in undergraduate education is growing rapidly in India (Penprase 2015) and in China. The neologism 跨学科 kua4xue2ke1—literally "across subjects"—has been discussed in Chinese journals of HE since at least 1986 (liu zhong lin 1986) and has joined various translations of "liberal arts" in the lexicon, but 跨学科 as an educational concept is still relatively new compared to "interdisciplinarity" in US HE.

38.3 Structure of the Arts and Sciences BASc Curriculum

Study time on the BASc is divided 50–50 between a Core and one of four different Pathways. There is a 3-year version of the degree, all completed in the UK, and a 4-year version in which students spend their third year studying abroad at a partner university.

The Core contains approximately 15 inter- (or cross- or post-) disciplinary modules, six of which are compulsory for all students and the remainder of which students must choose between as electives (Table 38.1).

The four disciplinary Pathways divide up UCL's entire academic curriculum into four broad bands:

- Cultures (Humanities and Arts);
- Societies (Social Sciences, Law);

Table 38.1 Core Curriculum of Arts and Sciences BASc

Core	
Compulsory Core Modules	Interdisciplinary Electives
Approaches to Knowledge: An Introduction to Interdisciplinarity	Data Visualization
Exploring Complexity: Quantitative Methods	Evolution and the Human Condition
Interdisciplinary Research Methods	Qualitative Thinking
The Knowledge Economy (a "real-world" consultancy project, in the final year of the degree, on which all students work in small teams to assist a local business);	Technology, Heritage, and Material Culture
Final year (capstone) interdisciplinary dissertation	Migration and Health
Foreign language (students choose their own language to study).	Object-Based Learning: Museum Stories
	Psychology and the Real World
	Understanding Cities
	Environmental Sociology

- Health and Environment (Health and Environmental Sciences);
- Sciences and Engineering (Hard Sciences, Maths, and Computer Sciences).

A timetable schema for an individual student is given in Table 38.2.

The course adopts the "major" and "minor" vocabulary from the United States, with students majoring in one of the pathways and minoring in another. However, one selling point of the degree is that students must take at least *some* nonscience and *some* science (or maths) throughout the program. For example, if a student majors in cultures or societies, they must minor in health and environment or sciences and engineering (and vice versa) with a ratio of courses of approximately 3:1 major to minor throughout their time on the program. The degree also contains full support for an internship (work placement), usually carried out after the second year of study.

There are many innovations in teaching and learning in the program, including teaching using flipped lectures, multimedia work, team projects, engineering modules with no math (!), object-based interdisciplinary learning, and so on. In several instances, students work on less structured or open problems, now thought to successfully foster several higher-order thinking skills (Hogan et al. 2015).

The UK context can be seen as partway between that of the United States, where interdisciplinarity is more widely understood, and the global East and South, where the concept has generally not been part of the educational tradition. Amid talk of "educating for global leaders," "finding the researchers of tomorrow," and other notions given as valuable outcomes of IE, the students on the program at UCL are well placed to give a perspective on a concept new to them but not problematically unknown. The voices and words of these students are likely to resonate wherever new interdisciplinary ventures in undergraduate education are attempted.

Table 38.2 Arts and Sciences BASc Timetable for Students

	Core				Pathway			
	0.5 course units	0.5 cu	0.5 cu	0.5 cu	0.5 cu	05.cu	0.5 cu	0.5 cu
Final	The Knowledge	Dissertation	Dissertation	Language	Maj	Maj	Maj	Min
Year Abroad (on 4-Year Program) Internship								
Year2	Object-based learning OR Making Value Judgments: Qualitative Thinking OR Quantitative Methods II	Interdisciplinary Electives	Option to take further module in Major Min	Language	Maj	Maj	Maj	Min
Year1	Approaches to Knowledge: Introduction to Interdisciplinarity	Interdisciplinary Methods	Quantitative Methods and Real-World Problems	Language	Maj	Maj	Maj	Minor

Table 38.3

Interview Questions for Arts and Sciences Basc Students

1	Please could you introduce yourself? What is your name, what Pathway are you studying on, and which modules are you taking this year?
2	What focus, if any, do you feel your studies are taking?
3	What does "interdisciplinarity" mean to you?
4	What particular challenges have you faced as a student on this interdisciplinary program running, as it is, in an institution maintained on disciplinary lines?
5	How important has extra study, in particular the use of online forums, MOOCs, etc., been in helping you "bridge the gaps" of an interdisciplinary program? Can you give any examples?
6	What intellectual qualities would you say a student needs to be successful on this course?
7	And personal qualities?
8	What advice would you give a student about to join the program?
9	How do you see the future of interdisciplinary learning?

38.4 Method

In summer 2014, after they had completed 2 years of undergraduate work, Carl Gombrich invited 13 students to visit him individually in his office to be interviewed about their experiences on the program and to discuss their ideas about interdisciplinarity. The questions were sent to students in advance. The interviews were semistructured. There is no attempt to take a random sample or avoid selection bias. On the contrary, we are interested in what successful students think about their program. More quantitative studies, as well as comparative studies of different cohorts involving students on noninterdisciplinary programs would be of considerable interest for future research.

The topics were chosen to reflect a gap in current research: *What do students in the UK think about learning on an interdisciplinary undergraduate program?* It would not add much value to over-egg methodology here, but the approach is broadly that of grounded theory—that is, tagging of themes as they emerge for the purpose of later analysis. All students were asked the key questions shown in Table 38.3, but there was room for more exploratory and free conversation. Most interviews were around 40 minutes, with the shortest at 27 minutes and the longest at 53 minutes.

Although on an English program at an English university, the students have diverse backgrounds. By nationality, five were English, three German, one Swiss, one Croatian, one Saudi, one Spanish, and one Polish. This is close to the nationality breakdown of the cohort, which is roughly 50% UK, 25% European (non-UK), and 25% other. The students were between 18 and 21 years old.

38.5 Results of Interviews

This paper mainly considers the student responses to questions 3, 6, 7, 8, and 9 in Table 38.3. These questions emerged as giving the most interesting perspectives on interdisciplinarity from the point of view of the learner, and link to research in educational psychology and the learning sciences.

In the analysis below, the students' names are changed. The responses are edited for intelligibility. They are arranged around four themes that were raised repeatedly by the students:

- Openness and open-mindedness
- Creativity
- Bridging
- Multiple-perspectives and perspective-taking

Collectively, students described these four attributes as important for the individual interdisciplinary learner and for the success of interdisciplinary groups. The individual and the team dimensions of interdisciplinary research have been highlighted by, for example, Barry and Born (2013). These dimensions indicate the need for multilevel models of interdisciplinary learning and problem solving. Openness and creativity are important attributes of the individual that may support the ability to take on multiple perspectives and support bridging across disciplines and knowledge domains. The ability to combine perspectives and bridge across disciplines may also entail a dedicated focus on group facilitation and collaborative learning within interdisciplinary teams. These issues and related challenges are discussed below.

38.6 Openness and Open-Mindedness

Several students answered the questions, "What intellectual/personal qualities do you need to be successful on the course?" by highlighting the importance of openness to experience:

> ANELIE: *You need to be very open-minded.*
> GEORGE: *Well the obvious one would be to be open-minded.*
> MIKA: *Well, I guess just open-minded, and accepting.*

Another student highlighted a possible developmental trajectory in this regard, with learning to be open-minded seen as one of the first major challenges in the program:

> VICTOR: *I think what I had to learn probably in the beginning is to be very open-minded about everything.*

Josephine suggested that openness, as a trait or disposition, may be more important than specific academic skills and an attribute that interdisciplinary program directors may want to cultivate:

> *It's hard to say exactly what qualities you need in terms of academic qualities in essay writing or whatever. I think it's more about openness. [Other] departments will start up interdisciplinary programs . . . because . . . it's a way of opening up people's minds to new things and to new ways of working.*

Eva talks about the importance of openness in addressing challenges that might be thrown at you when encountering several disciplines at once:

> *You have to be open and say I am going to talk to the professor if I don't understand. I think that is really important trait to have : to be open.*

Overall, students see openness as important for individual, interpersonal, and institute success in IE. This resonates with research in the field of personality and educational psychology. Notably, Openness to Experience is one of the "Big 5" personality traits used to describe people who are willing and often eager to encounter a wide variety of ideas, feelings, and activities. Openness is assessed through six traits, or facets: Openness to Fantasy, Aesthetics, Feelings, Actions, Ideas, and Values. McCrae and Costa (1997) proposed that Openness is seen in the breadth, depth, and permeability of consciousness, and in the recurrent need to "enlarge and examine experience" (p. 826). Altaras-Dimitrijević (2012) found that intellectually gifted students score higher on Openness to Fantasy, Aesthetics, and Ideas, but other studies have reported weak correlations of .20 to .26 between openness and Scholastic Aptitude Test (SAT) performance and GPA scores (Noftle & Robbins 2007).

38.7 Creativity

Related to the focus on openness, several students responded that "creativity" was an important quality to have in the program but also linked this to notions of interdisciplinarity itself and to reflections on whether creativity and related attributes could be taught.

> MARIA: *The intellectual qualities you need?—Creativity definitely, creative problem solving all around, also because with Core modules you always need to see stuff from different perspectives . . . in fact, all the modules which are tailored for BASc people, like our new engineering courses. I think they really push this creative problem solving.*
>
> AND LATER: *The reason why I chose arts and sciences was because I thought it would be a way in which I could be creative and technical at the same time. I think there's also a level of curiosity plus hard working as the ingredients to this creativity. It's a matter of wanting to dive into many different things, which is curiosity, and hard-working, having the ambition to dive to a point at which you can be—I don't know . . . critically creative—create a solution as opposed to write down something that you've memorized from before.*

The idea of being "critically creative" resonates with calls for the development of both critical and creative thinking skills in students, that is, to support insight-based reasoning, or what Wertheimer called productive thinking (Wertheimer 1959). Wertheimer, the famous Gestalt psychologist, suggested that only insightful reasoning could bring true understanding of conceptual problems and relationships. Recently, there have been calls for the development of mindful, critical, and collaborative thinking in team-based problem-solving situations, which imply new modes of collaborative creativity in interdisciplinary contexts (Hogan et al. 2014). Creativity scholars have long argued that the standard education model is largely a *transmission and acquisition* model whereby knowledge (i.e., facts and procedures) is transmitted in increasingly complex chunks by teachers in a regimented and structured manner. Students are obliged to acquire, memorize, and later recall this knowledge in an examination context. It is argued that the byproduct of this model is a creativity deficit in students, who ultimately fail to reach their full potential (cf. Beghetto & Kaufman 2010). As interdisciplinary degree programs are relatively new, students entering the program may only have experience with the standard education model and may therefore need support to develop creativity, critical thinking, and related metacognitive skills both in individual and group project contexts.

The discussion of creativity came up with Josephine in a rather interesting context. She had become quite passionate that we should not try to "define" interdisciplinarity too tightly. She felt that inherent in the notion of interdisciplinarity was an openness and creativity that would be diminished by being too prescriptive.

> JOSEPHINE: *Can't you get around this problem of making specific marking criteria for interdisciplinary work along the lines of basically using code words such as "innovative" and "creative"; because to me that's what interdisciplinary is and has been. Surely you can make that a learning outcome?*
>
> INTERVIEWER: *You'd leave it as open as that? I mean that's very hard to achieve because one is required to set targets and outcomes in today's educational culture. Is it enough to just say the outcome for this module is that you will have made some creative connections and done some innovative work?*
>
> JOSEPHINE: *I think that surely it is.*

This line of thinking may have implications for how teaching staff negotiate the curriculum and learning outcomes with students in future versions of the interdisciplinary degree program. According to Boomer (1992, p. 13), "if teachers set out to teach according to a planned curriculum, without engaging the interests of the students, the quality of learning will suffer. Student interest involves student investment and personal commitment . . . [and] negotiating the curriculum." The teaching styles of interdisciplinary instructors may need to be considered in this context. Notably, Zhang and her colleagues (Zhang et al. 2005) investigated the preferred teaching styles among university students in the United States and Hong Kong and found that students generally preferred that their teachers use creativity-generating teaching styles.

Alongside Josephine, Eva also strongly associates IE with creativity and "thinking outside the box":

> EVA: *What I got out from this Qualitative Thinking course is creativity, thinking outside the boundary. How I can apply something that does not link but maybe there is something interesting to find out when you bring the two together. Also thinking outside the box, which I guess is similar.*
>
> INTERVIEWER: *Thinking outside the box. Do you think this can be taught? Do you think everyone can make quite a lot of progress in thinking outside the box if they are obliged to or do you think some people don't have the . . . ?*
>
> EVA: *If they are motivated to do it. I think the course encourages you or asks you to, even. You have to go a bit outside what you are used to and you cannot just read a book and quote from that. We think the same thing that someone has done before because of the way the questions are asked, whereas on this course you are asked to link an idea to this new thing which no one has ever done before.*
>
> INTERVIEWER: *Can you explain more how the word "creativity" links to interdisciplinarity . . . ?*
>
> EVA: *I think in order to be interdisciplinary you have to have creative thinking because you apply a discipline that you were taught to completely different things. Even if the disciplines are not actually so different, you are taught that way from when you were really young. It takes a bit to go out of this thinking: "this is math," "this is economics," "this is physics," etc., and then link them back together. We made up the boundaries, but to get this out of our head it does need a sense of the creative: "How can I link this with that?" You need to have this innovative thinking.*

Finally, in this section on creativity, Tom reflects on creativity and the future of IE.

INTERVIEWER: *Are you are seeking those creative connections all the time because that's the sort of person you are, or is it something the program obliges you to do?*

TOM: *I think anyone can learn it, but I think some people are more predisposed to do it and those people are on this course. I think some people can be better at it but I don't think you either have it or you don't. There are some people who one would assume are very closed minded and, "I'm an economist," but then when you talk to them about psychology they get it. I've had conversations with people who will argue back and say, "No, but my subject is more important," but they'll still understand where I'm coming from.*

INTERVIEWER: *What do you see as the future for interdisciplinary education?*

TOM: *I think obviously interdisciplinarity will become more mainstream, that's for sure.*

INTERVIEWER: *Why?*

TOM: *Because employers will want it more and academics are realizing that one linear look at academia isn't very conducive to creativity. That I'm almost certain about.*

This student has been successful in gaining internships at a number of world-leading consultancies and other organizations and so has personal experience of what employers value.

Debate about the value of creativity in education has been ongoing for close to a century, with Dewey arguing as early as 1916 for the importance of keeping a creative attitude alive in children (Dewey 1916). More applied research is needed that focuses on the benefits of actionable methods by which teachers can introduce and nurture creativity in the classroom. It is clear from the available research that creativity is important for core educational outcomes. For example, recent research (Putwain et al. 2012) has shown that creative self-belief is positively related to intrinsic motivation. Additionally, Corpus et al. (2009) have demonstrated that intrinsic motivation improves academic achievement and that both motivation and achievement influence one another in a positive and reciprocal manner. Therefore, an interdisciplinary degree curriculum that negotiates learning outcomes with students, nurtures creative self-belief, and cultivates intrinsic motivation in students may result in higher academic achievement. However, a key challenge for us is how best to understand the unique nature of creativity in an interdisciplinary training context and how best to cultivate creativity in a way that facilitates interdisciplinary work. The idea of bridging may be particularly important in this context.

38.8 Bridging

The concept of "bridging" is widespread in the interdisciplinarity literature. The importance of this concept is borne out in several student responses:

INTERVIEWER: *What has interdisciplinarity come to mean to you at this stage in your studies?*

MARIA: *I think it's bridging a gap that is massive and obvious.*

INTERVIEWER: *Between existing disciplines?*

MARIA: *Yes. I feel a bit cliché saying this, but in my environmental physics they describe economists as having a completely different view, so physicists "know better." But really they have completely different approaches but they're all in the same chain.*

This focus on bridging raises questions about the strong focus on the individual learner in the standard education model, a model which implies that one person, or one discipline, is better than another. It also leads us to question the focus on the individual as the fundamental source of creativity, and how creative, productive, and systems-level thinking can arise at the group level. Clearly, a focus on groups and team-level performance can be critical for some types of interdisciplinary work (Hogan et al. 2015).

Adriano provides an account of the interdisciplinarian as essential bridge-builder and facilitator in projects that require teamwork.

> ADRIANO: *I think all of our group work here at BASc shows that people with different skill sets working together is important. Sometimes people speak the English language but they can't speak the same academic language. I see the way scientists sometimes teach and they will just bore humanities people and switch them off. The other way round humanities people will try to go really deep into a subject and it will put others off. You can see that interdisciplinarity means you learn the language of both and you are a bridge. You connect the two together, and that, I think, is a way which will change the way that people work.*
>
> INTERVIEWER: *There are places for people like that out there in the world, do you think?*
>
> ADRIANO: *Every team will need someone who can make the connection, who can say to the person with the physics degree, "Listen you made an interesting point but you can maybe do it this way to make your ideas a bit more . . . ." Or the other way is work with specialized people and say, "This person from this discipline has a good, interesting idea and I will try and explain to you how it works." I think knowledge is like a web, there are different fields and we become like the strings which connect each of them together. We are making loads of infinitesimal connections between them.*

These comments highlight the importance of group facilitation in many real-world contexts. Graduates of interdisciplinary programs may be natural candidates for dedicated training as interdisciplinary group facilitators. Notably, in the context of a discussion on facilitating collective intelligence (CI), Hogan et al. (2014) argue that the central role of the CI facilitator is to create and sustain an inclusive and participatory climate through structured dialogue. It is critical to encourage a variety of perspectives while disallowing premature evaluation. The facilitator asks participants to adopt a posture of individual and collective willingness to listen to and learn from each other. While it is not expected that everyone will agree with every aspect of the final CI products, with good facilitation participants are generally committed to and willing to support the work of the group.

More generally, bridging implies a focus on collaborative learning. In educational settings, where foundational skills in collaborative learning may be developed for application in future work settings, various forms of collaborative learning methodologies predominate. Many of these methodologies, especially those which facilitate collaborative problem-solving, are metacognitive in nature. Metacognitive collaboration refers to the process of team or group members thinking about, and reflecting on, how their team processes information, works on problems, and feels about the collaborative process. Effective metacognitive collaboration requires the coordination of a number of factors: effective facilitation, feedback, and instruction regarding the collaborative process and goals; cultivation of enhanced team functioning in the collaborative context, including the promotion of cooperative, exploratory discourse; and the use of tools and methodologies that facilitate group coherence, the management of complexity and group problem-solving (see Hogan et al. 2015for a review).

38.9 Multiple Perspectives and Perspective-Taking

Anelie is taking a range of modules across the social sciences and the humanities and feels this has given her different perspectives on her work:

> ANELIE: *[Interdisciplinarity means] looking at problems from different perspectives. For me, that was how people express themselves through art, as I saw studying anthropology of art, but also how scientists look at it, and the psychology of it.*

Georgie has a particular interest in mathematics, but she is also strong in more discursive work in the humanities and social sciences:

> INTERVIEWER: *You have managed to make connections between these very different areas of thought. Is that what interdisciplinarity means to you at the moment?*
> GEORGIE: *For me personally, yes. It would be, with math for instance, going away from just the calculations and the notation and just looking at them from a perspective that probably someone doing straight maths wouldn't look at it from.*

Nadia is strong in social sciences and humanities, but has also some technical skills in coding, which she uses for data mapping of cities. She has secured both a prestigious graduate legal training contract and, separately, the possibility of a postgraduate research position working on smart cities.

> NADIA: *The Arts and Sciences course taught me to listen, I mean to be more objective in my judgment, because I always try to imagine why this person is saying this, why this person has this viewpoint. Well, it taught me that I'm not always right.*
> INTERVIEWER: *That's really interesting you say "objective," because, particularly in the first year I think, many students think the opposite; they think that in being obliged to think about other perspectives they become actually more relativistic. . . . Have I understood you correctly?*
> NADIA: *Yes, yes. I think that it absolutely works. Also the ability that the course taught me really to listen to viewpoints I don't agree with is quite useful in relations with other people, even. I've become really more able to understand others and why they are doing what they are doing.*

Adriano also articulates that interdisciplinary learning gives you academic perspectives and links this to how he sees developments in the workplace:

> ADRIANO: *For one essay I did a lot of looking into Japanese, which is the language I study on the BASc. I looked at the history of Japanese, I examined the actual Japanese language itself, and explored the Japanese language from the perspective of linguistic theory. You want to explore a different field from a different perspective. You could say that is interdisciplinarity.*
> *There is a massive push for interdisciplinarity in the workplace. By having different ways of thinking, different perspectives, you can find out what really works and what doesn't work. That's why interdisciplinarity is important, it is a different perspective. That is why employers like it so much.*

Sammy, who studies a combination of design, psychology, and the humanities, advises friends studying very different disciplines. She regards herself as not a natural essay-writer but, through her interdisciplinary studies, has acquired generalist skills in perspective-taking, which she can apply in disparate disciplines.

SAMMY: *I can say to them, my flatmate who's studying law and I'm like, "You haven't covered this in your essay." Not that I know a lot, but kind of.*

INTERVIEWER: *So what's going on?*

SAMMY: *Well you pick up so much stuff throughout studying all the things on this course, you pick up bits everywhere. I've got History of Art students in my flat as well. So they're sitting there talking about art and stuff, and because I did a study on the Avant-garde I can now contribute, and I'm like, "How about this?" You get a different perspective.*

The ability to take on different perspectives and see the world from the perspective of others is a fundamental cognitive and social skill that can be fostered in educational environments and can impact educational outcomes (Schultz et al. 2001). Even in the absence of dedicated "creativity training," immersion in a culture of interdisciplinarity may be sufficient to promote creativity and openness in students.

38.10 Discussion

The interviews corroborate several positive theoretical notions about the value of learning with multi- and interdisciplinary curricula. However, even if we take the students' words at face value, we still have an "elephant in the room" regarding IE: Which way does the causal arrow flow? Or, indeed, might it flow both ways? Specifically, is it the case that (1) IE can foster the traits that we may see as desirable for graduates? Or is it simply that (2) students who already possess such traits are attracted to such programs? The students themselves report a range of opinions on this matter—and self-reporting may not be reliable.

Let us call (1) the strong position and (2) the weak position. We can, initially, take the weak position on IE without denigrating its value. For if such an education is indeed attractive to bright students with such traits, why should universities not provide such a possibility for them? One would have to make an argument that the outcomes of such an education were negative in order to conclude that universities should not offer such programs. But, in fact, there is evidence to support the view that graduates outcomes of such programs are far from negative. Students educated on interdisciplinary courses are well placed in the current job market and are in a strong position to progress to research careers in academia (UCL 2014).

This alone is sufficient reason, in our view, for offering interdisciplinary programs. But is it possible to argue for the strong position, that such an education can, indeed, foster creativity, openness, perspective-taking, and so on? Although this small study is suggestive, the psychological gains of specifically interdisciplinary courses are underresearched and there is potential for larger, more scientific studies.

38.11 Conclusion

This chapter is, itself, an interdisciplinary piece, synthesizing a discussion of interdisciplinarity in HE from the students' perspective with experimental results from the psychology of education. As such the chapter is broad-brush in parts. We propose both that this qualitative study of the student experience points to the necessity of more research in the psychology of interdisciplinary learning and that the results of the study offer a useful vocabulary and conceptual scheme for the justification of interdisciplinary programs. Indeed, it is likely that these two themes will come together in future work, for if the benefits of interdisciplinary learning can be put on a stronger scientific footing, the conceptual scheme and justification for such learning will likely follow.

Taken in its totality, interdisciplinary undergraduate education is a vast and complex area of research. It has its passionate advocates and its detractors. For those fixated on "instrumental" outcomes of HE and the learning of tightly defined skill sets in known domains of knowledge, it is perhaps surprising that we are seeing the growth of this sort of education in the UK, in mainland Europe, and in the growing powers of India and China. However, as this paper suggests, many of the outcomes of IE are what we might call "meta-instrumental," that is, they involve the learning of metacognitive skills and the fostering of such dispositions as open-mindedness, creativity, bridge-building, and perspective-taking, which may be applied more widely than domain-specific knowledge.

If we are to value such dispositions and traits, as numerous actors in education, industry, and government say that we should, then the voice of students studying on such programs is an important testimony and can help as a guide for future developments.

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CHAPTER 39

INTERDISCIPLINARY PEDAGOGIES IN HIGHER EDUCATION

DEBORAH DEZURE

39.1 Introduction

The second decade of the twenty-first century has seen dramatic increases in the adoption of intentional and explicitly stated integrative and interdisciplinary goals for student learning, methods to teach and assess those goals, and the development of practice-oriented resources to assist instructors and students engaged in this complex endeavor (Boix Mansilla et al. 2009; Repko 2012; Repko et al. 2014). These increases have been fueled by the Association of American Colleges and Universities (AAC&U) LEAP initiative, which has promoted liberal learning goals for undergraduate education, including integrative and interdisciplinary learning. Reform efforts in STEM education (Project Kaleidoscope 2011), doctoral education (Manathunga 2012), and education in the health sciences (McMurtry et al., this volume) have echoed employers' calls for graduates with integrative and interdisciplinary skills to solve unscripted, real-world problems that invite and require interdisciplinary and team-based solutions (T-Summit 2016).

Federal funding agencies have focused on the importance of interdisciplinary research, which in turn has spawned a burst of scholarship on interdisciplinary research collaborations and communications to better understand how productive interdisciplinary teams do their work (O'Rourke et al. 2014). We are moving from theory to practice with intentionality. We are seeing evidence of an emerging consensus on what constitutes interdisciplinary learning as well as enhanced alignment among learning goals, teaching methods, and assessments that characterizes effective instructional design (Szostak 2013). In sum, interdisciplinary teaching and learning are moving in from the margins to the mainstream of American higher education.

Although there is greater consensus about effective instructional practices, interdisciplinary teaching and learning do not claim any unique set of pedagogies. Instead, interdisciplinary teachers employ an array of instructional methods to support interdisciplinary learning outcomes. This chapter identifies several productive pedagogies, providing the background

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and context in which they emerged, and their relevance to interdisciplinary teaching and learning today. These include:

- advances in cognitive science, neuroscience, and the scholarship of teaching and learning that support active and experiential approaches to teaching and learning;
- efforts to promote diversity in higher education through multicultural curricula and inclusive pedagogies designed to ensure that all students can succeed;
- accreditation, external calls for accountability, and the assessment movement, which focuses attention on what students know and can do upon graduating;
- the shift from mastery of content to competencies, and the importance of student learning outcomes generally and integrative and interdisciplinary learning outcomes specifically;
- the emergence and development of pedagogies that support the skills needed to engage in interdisciplinary problem solving;
- the emergence of the World Wide Web, the Internet, and instructional technologies;
- the growth of faculty development and teaching centers to disseminate pedagogical innovations;
- the proliferation of research on interdisciplinary research collaborations and communications, including the science of team science;
- technology-enabled research methodologies and digital tools; and
- new developments in interdisciplinary teaching, learning, and assessment.

39.2 Defining Interdisciplinary and Integrative Learning

Interdisciplinary outcomes for student learning focus on solving complex problems that are too broad to be addressed through a single disciplinary lens (Klein 1990). Attention is also given to the related abilities to analyze problems from several perspectives, including disciplinary ones, to compare and contrast, to critically analyze resources, to place problems and solutions within a larger context, to develop critical arguments, to empathize with multiple perspectives and stakeholders, and to tolerate ambiguity and complexity (Haynes 2002). Boix Mansilla (2005) defined the goal of interdisciplinary understanding as:

> The capacity to integrate knowledge and modes of thinking in two or more disciplines to produce a cognitive advancement—e.g., explaining a phenomenon, solving a problem, creating a product, raising a new question—in ways that would have been unlikely through single disciplinary means. (p. 4)

One additional term, "integration," requires clarification because it is used frequently in defining interdisciplinary student learning outcomes. Interdisciplinary learning is a special case of integrative learning, requiring several of the same skills and habits of mind. The definition of integrative learning provided by the Association of American Colleges and Universities & the Carnegie Foundation for the Advancement of Teaching (2004) is "an understanding and a disposition that a student builds across the curriculum and co-curriculum, from making simple connections among ideas and experiences to synthesizing and transferring learning to new, complex situations within and beyond campus."

Integrative learning comes in many varieties: connecting skills and knowledge from multiple sources and experiences; applying theory to practice in various settings; using diverse and even contradictory points of view; and, understanding issues and positions contextually. Significant knowledge within individual disciplines serves as the foundation, but integrative learning goes beyond academic boundaries. Integrative experiences often occur as learners address real-world problems, unscripted and sufficiently broad to require multiple areas of knowledge and modes of inquiry, offering multiple solutions that benefit from several perspectives.

These are useful working definitions for instructors. They can help faculty and students differentiate interdisciplinary learning outcomes from other forms of discipline-based problem solving and integrative learning. However, these definitions are not widely understood or employed by instructors and not everyone concurs that interdisciplinary learning should be deeply rooted in or dependent on disciplinary knowledge. For a discussion of interdisciplinary definitions, see Klein (this volume).

Many faculty use the term "interdisciplinary learning" variably and loosely to mean: (1) multidisciplinary learning outcomes that engage students in the study of two or more disciplinary perspectives on a problem or phenomenon without producing an integrated analysis or solution, (2) cross-disciplinary learning in which one discipline is used in the service of another, or (3) protodisciplinary outcomes that enable students to draw on resources without knowledge of the disciplinary modes they represent. Other faculty describe their courses as interdisciplinary when they present their own interdisciplinary syntheses of disciplinary materials without formal explication or instruction on how to employ disciplines to arrive at integrated interdisciplinary solutions, while some assign interdisciplinary tasks to students without instruction on how to proceed or what interdisciplinary work entails.

The definitions by Klein (1990) and Boix Mansilla (2005) are deeply rooted in knowledge of the disciplines and disciplinarity. While many faculty embrace these definitions, there are others who challenge the centrality of disciplinary knowledge inherent in these definitions, preferring interdisciplinary approaches to teaching and learning that reduce the hegemonic influence of the disciplines in higher education, focusing instead on general skills in critical and analytical thinking and integrative problem solving. Nonetheless, the definition by Klein is widely used and cited by those engaged in interdisciplinary work. Many more faculty are engaging in interdisciplinary work today, entering through disciplinary pathways, often prompted by federal funding sources for research, such as the National Science Foundation (NSF) or National Institutes of Health (NIH), and are looking for definitions to guide and describe their research and teaching.

More recently, there have been calls from higher education, industry, government, foundations, and professional associations for college graduates who will be *T-shaped professionals* who have deep disciplinary knowledge in at least one area, an understanding of systems, and an ability to function and collaborate across a variety of different disciplines and social, cultural, and economic boundaries (T-Summit 2014). These calls for T-shaped professionals add new urgency and relevance to calls for interdisciplinary learning, reframing it to attract new stakeholders outside academia as advocates for interdisciplinary learning.

39.3 The Context in Higher Education

Significant changes have occurred in teaching and learning in higher education during the past 45 years. These changes were propelled not by a single engine, but by many developments acting as levers—shaping attitudes, creating opportunities, and promoting shifts in policies, practices, and programs. Together they provided the critical mass to enable higher education to make unprecedented strides in the development of teaching and learning generally and interdisciplinary teaching and learning specifically (DeZure 2000, p. 423).

Interdisciplinary curricula and programs are proliferating in disciplinary departments (with the ironic reduction in interdisciplinary studies programs), offering compelling evidence that interdisciplinary curricula are increasingly mainstream in higher education (Augsburg & Henry 2009; Klein 2010). With the proliferation of interdisciplinary programs and courses, there has been an increased interest, particularly by faculty new to interdisciplinary pedagogy, in how to design, teach, and assess them. This enables instructors to document that students have attained competence in interdisciplinary problem solving and integration.

While interest is high, institutions and faculty continue to struggle with how to meet this challenge. In a study of 139 institutional applications to participate in a national project titled "Integrative Learning: Opportunities to Connect," designed to promote integrative and interdisciplinary learning, DeZure et al. (2005) found that campuses that already employed numerous integrative and interdisciplinary curricular and pedagogical practices nonetheless had fundamental questions about what constitutes integrative and interdisciplinary learning, which teaching methods are most effective, and what methods can be used to assess and document student mastery. In sum, interdisciplinary teaching and learning are alive and well in higher education, and there are models to inform instructional decision-making; but there is much more work to fulfill their potential to enable graduates to solve the challenges we face as a global society.

39.4 Levers for Change

What were the levers that supported the growth of interdisciplinary teaching and learning in higher education? For an expanded discussion of these levers for change, see DeZure, 2010. Advances in cognitive science and neuroscience have affirmed the efficacy of teaching methods that actively engage students, requiring students to be active agents in the learning process rather than passive recipients of information. Students should interact with the materials to be learned and reflect on their work to reinforce their learning and to promote metacognitive skills. Cognitive science also underscores the need for multimodal approaches to teaching, including experiential learning and peer interaction.

Insights from brain research reinforced the proliferation of approaches for active learning, including collaborative, cooperative, and team-based learning; case studies; role-playing, simulations, and serious gaming; problem-based learning; discovery-based learning; and field experiences, including internships, service learning, and study abroad. While these methods can be enacted through a disciplinary lens, they also invite multidisciplinary perspectives and opportunities for interdisciplinary integration. The more the pedagogy engages students in experiences based in the complexities of the real world, the more there is a need to employ interdisciplinary approaches to problem solving and authentic assessment.

In the mid-1990s, new conceptions of the social construction of knowledge took hold in higher education, particularly in the humanities and social sciences, leading to the emergence of constructivist teaching and assessment methods. In constructivist methods, students actively construct knowledge with their peers, often in the context of collaborative and cooperative learning groups. These methods differ, particularly with regard to the level of structure and guidance provided by the instructor. But both approaches involve working with peers to construct knowledge, invite multiple perspectives as part of the critical examination of solutions, and require analysis and synthesis skills. These methods are learner-centered, although the degree to which power and authority shifts from teacher to students can vary. Collaborative learning often has looser structure with low levels of instructor intervention. Cooperative learning often has tighter structure with high levels of instructor design and oversight.

Collaborative learning (Bruffee 1995) is a philosophy of interaction with roots in the humanities in which individuals are responsible for their actions, including learning and respect for the abilities and contributions of their peers. It is not primarily concerned with converging on a correct or predetermined answer. Rather, it is concerned with the nature of reasoning, questioning, and informed conversation, or what Bruffee has called the "conversation of mankind."

Cooperative learning (Johnson et al. 1998) is a structure of interaction that involves students working in teams to accomplish a common end-product or goal and includes all the following elements: positive interdependence; individual accountability; face-to-face interaction; appropriate use of collaborative skills; and group processing. Cooperative learning emerged from the social sciences, particularly work with primary and secondary school students who benefited from high levels of structure and teacher guidance.

Although Bruffee emphasizes that originally collaborative learning was designed for adults engaged in the higher-order critical thinking skills of reasoning and questioning, and cooperative learning was designed for younger students mastering foundational knowledge, both approaches have proven to be highly effective with students in higher education across the disciplines for a range of learning outcomes. Both have a place in promoting the skills inherent in interdisciplinary analysis and problem solving. Methodological borrowing is common across these two models based on the nature of the students, the disciplinary paradigms, and the goals for learning. Instructors may also take a developmental approach to these models. This provides beginning students with the tighter structure of cooperative learning for introductory group work and mastery of material, and more advanced students with the looser structure and more open-ended critical thinking goals of collaborative learning.

A "jigsaw" is a highly structured model of cooperative learning that is particularly well suited to interdisciplinary problem solving (DeZure 1989). It breaks down complex problems into more manageable pieces and presents them in a sequence that students new to interdisciplinary studies can more readily handle. The jigsaw method has two stages. In the first stage, students are assigned to primary groups in which they address one dimension of a large, complex problem. Each primary group focuses on a different dimension of the same problem. In the second stage, students are dispersed into secondary groups comprising one member from each of the primary groups. In these secondary groups, students share the insights from their primary groups and then work collaboratively to integrate their insights into a holistic solution to the complex problem.

For use in interdisciplinary problem solving, in stage one, students are assigned to primary groups in which each group studies a different disciplinary perspective on a complex problem. In stage two, secondary groups endeavor to bring together their disciplinary insights into an integrated interdisciplinary solution to the larger problem. The model is time-consuming, but it models the systematic and challenging steps in interdisciplinary problem solving and demonstrates the relationship between discipline-based and interdisciplinary solutions.

The sciences, technology, engineering, math, and medicine have long been using problem-based learning (PBL) and discovery-based and inquiry-based learning, which resonate as variants of the scientific method. These approaches also reinforce the integration of multiple sources of information and perspectives, higher-order critical thinking skills, and student-centered learning in groups and teams.

Beginning with open admissions and affirmative action in the 1970s, efforts to promote diversity and multiculturalism in higher education led to the identification of "inclusive pedagogies." These were characterized by approaches that invite multiple perspectives and discussion to ensure all voices are heard. Increased diversity brought students with more varied life experiences who wanted to share their perspectives. Dialogue, panel discussions, reflective journals and narratives, and more relational and feminist pedagogies were often preferred by underrepresented groups, just as women were introduced to structuring the expression of different positions toward an issue—promoting empathy and understanding for other viewpoints, critical analysis, and synthesis.

The proliferation of academic service-learning (i.e., tying academic course goals to required service experiences in the community) and study abroad further broadened the exposure of students to diverse populations and perspectives. These experiences required students to integrate learning from in-class and out-of-class with exposure to diverse people in real-world contexts. One of the hallmarks of good practice in service learning is critical reflection (often in the form of student journaling and a culminating reflective essay) to integrate multiple sources of insight and experience. All these approaches promote skills required for interdisciplinary integration and solutions relevant for real-world contexts.

Beginning in the late 1960s, writing across the curriculum (WAC) underscored that effective writing differs according to its purpose, audience, and disciplinary context. Advocates for WAC proposed that writing be taught and assessed by faculty across the disciplines and not relegated entirely to a single freshman composition course, often located within an English department. In response, institutions established upper-division intensive writing courses in the disciplines to assist students to learn the paradigm of writing in at least one discipline beyond English, usually in their major.

By the mid-1980s, the assessment movement was emerging in American higher education, focusing on the articulation and assessment of student learning outcomes along with institutional accountability for their attainment. Initially driven by accrediting bodies, these efforts were reinforced by employers, who found that college graduates were weak in fundamental skills such as critical thinking, written and oral communications, quantitative literacy, civic responsibility, ethics, and teamwork—all core skills in the workplace. As institutions complied with assessment mandates, they began to conduct collegewide evaluations to identify outcomes they valued for their graduates, identifying the same crosscutting skills and attributes. These campus processes accelerated the shift in higher education from mastery of content to competencies, from passive to active pedagogies, from traditional testing methods to assess learning to more authentic methods that modeled and mirrored the complexities of the real world (DeZure 2000).

In their efforts to define critical thinking, campuses relied on Benjamin Bloom's *Taxonomy of Educational Objectives* (1956), focusing on goals in the cognitive domain related to levels of critical thinking—knowledge, comprehension, application, analysis, synthesis, and evaluation. These shifts reinforced the relevance of interdisciplinary problem solving and its capacity to engage students actively in the complexities of analysis, synthesis, and evaluation in addressing real-world problems.

Writing continues to be the primary means by which to teach and assess written communications and critical thinking generally and interdisciplinary critical thinking specifically. Interdisciplinary studies scholars developed a writing curriculum to teach and assess interdisciplinary learning and related critical-thinking skills. Haynes (2004), for example, identified a developmental sequence of writing assignments to assist students to support disciplinary analysis and interdisciplinary synthesis. The preliminary step was to help students identify the thinking of the disciplines under study: their assumptions, frameworks, foci, methods, and key questions. There are deep divides within disciplines that should also be identified. Subsequent assignments ask students to analyze a problem using different disciplinary frameworks, later moving to assignments that require comparison and contrast among the analyses. This is followed by integrative assignments in which students must draw on the methods and insights of several disciplines, reconciling them in an integrated approach.

One model proposed by Wolfe and Haynes (2003) for assessing interdisciplinary writing identifies four key dimensions: (1) drawing on disciplinary sources; (2) critical argumentation; (3) multidisciplinary perspectives; and (4) interdisciplinary integration. The evaluation of writing and interdisciplinary critical thinking continue to pose challenges to teachers of interdisciplinary studies, but scholars like Wolfe and Haynes (2003), and more recently Veronica Boix Mansilla et al. (2009) are clarifying this terrain.

In the twenty-first century, integrative learning has been identified as a core competence in undergraduate education. In 2004, the Association of American Colleges and Universities & the Carnegie Foundation for the Advancement of Teaching released its "Statement on Integrative Learning," defining "integrative learning" as the ability to integrate from multiple sources of knowledge and experience, that is, to integrate theory and practice, in-class and out-of-class learning, learning in general education courses and in the major, and learning across the collegiate experience.

Focus on integration is a response to concerns that the collegiate experience is atomized with too many fragmented experiences and too few connections. To promote integration, institutions are turning to student portfolios, particularly e-portfolios, keystone and capstone courses, learning communities, living-learning communities, and interdisciplinary courses. These provide opportunities for reflective writing and structured integrative assignments to enable students to bring together their disparate collegiate experiences and make meaning of them. Interdisciplinary pedagogies offer models of how to foster connected learning that leads to integration. These approaches honor disciplinary ways of knowing while enabling students to reach across their discipline-based coursework to create robust integrated interdisciplinary solutions to real-world problems.

Advances in instructional technology that make online resources readily accessible have also enabled innovations in interdisciplinary teaching and learning. Most online searches take students to resources that represent multidisciplinary and interdisciplinary perspectives, requiring them to think outside of disciplinary boxes. Technology also enables access to disciplinary and interdisciplinary experts from around the world to engage with classes and, more importantly, the ability to bring news and real-world challenges into classes as they occur. When students ask, "What caused this?" they are asking questions that often require interdisciplinary responses. Institutions are responding to world events by providing interdisciplinary discussions, websites, and podcasts.

Technology also provides the means to store student work for future reference, be it for integrative student reflection in capstone courses or student advising. In their study of integrative learning nationwide, DeZure et al. (2005) found that e-portfolios were identified most frequently as the method campuses were using (or planned to use) to promote, document, and assess integrative and interdisciplinary learning. E-portfolios have all the advantages of traditional portfolios that contain artifacts selected by the student to represent his or her learning and progress over time. E-portfolios take hard-copy portfolios to the next level, eliminating the problems of physical storage, retrieval, and transport, while expanding their multifunctionality and access by students, instructors and advisors. E-portfolios also can provide compelling data about student learning for purposes of interdisciplinary program review and institutional assessment.

39.5 New Approaches to Supporting and Evaluating Interdisciplinary Teaching

Faculty development programs and teaching centers have proliferated across the United States in the last 35 years, with recent increases in programs that explicitly support interdisciplinary teaching and learning. Supported by new research, these programs promote evidence-based instructional decision-making and the scholarship of teaching and learning (SoTL), that is, research on one's teaching and its impact on student learning that is critiqued by peers and made public. For example, for several years the Center for Research on Learning and Teaching at the University of Michigan sponsored a year-long facilitated cohort program, Interdisciplinary Faculty Associates, to enable faculty teams to study the research on interdisciplinary teaching and learning, design interdisciplinary team-taught courses, and produce course portfolios documenting their experiences and student learning.

Although individual faculty often employ interdisciplinary approaches in their teaching, many interdisciplinary courses are team taught by faculty with expertise in different disciplines. Team teaching has the potential to be a powerful source of interdisciplinary learning, allowing students to witness how experts from different disciplines approach issues and how they negotiate integrative solutions between them. Interdisciplinary faculty teams have to determine the degree of integration they wish to use and how it will impact their planning, curricular choices, instructional methods and delivery, assignments, and assessment practices. Having faculty present their disciplinary perspectives in serial fashion is not sufficient. If students are to engage in complex intellectual tasks to integrate the insights of different disciplines, then faculty should join in this endeavor, modeling it and sharing the difficulties and the richness of doing so.

New approaches to documenting and evaluating teaching go beyond the use of student ratings of instruction to enable faculty to represent the complexity of their instructional efforts and their impact on learning. These newer forms of peer review are appropriately multidimensional, including teaching portfolios, course portfolios, and SoTL. The proliferation of these approaches is an important development for instructors who teach interdisciplinary courses, for they enable instructors to clarify the complexity of interdisciplinary teaching and learning to their disciplinary colleagues and administrators. Course portfolios are particularly well suited for documenting interdisciplinary courses by individuals or teams. They enable instructors to describe the context, goals, and design of the course; the actual enactment of the course; and recommendations to improve the course and enhance the institutional climate to promote interdisciplinary studies.

The movement to promote SoTL seeks to foster research on teaching and learning, to open it to critical review, and to make it public so others can build on it. Course portfolios provide an important model for the scholarship of *interdisciplinary* teaching and learning (SoITL) because they meet all the criteria for SoTL work and are able to document the complex processes by which faculty and students engage in interdisciplinary problem solving. Course portfolios are now available in online repositories (Bernstein et al. 2006). Beyond institution-based faculty development, there are national associations that provide excellent faculty development seminars, resources, and access to networks of peers committed to interdisciplinary teaching and learning. These include the Association for Interdisciplinary Studies (http://www.ais.org), AAC&U (http://www.aacu.org/), and Project Kaleidoscope (https://www.aacu.org/pkal)

Faculty development focused on interdisciplinary endeavors is increasingly being supported by external funding agencies, for example the NSF and NIH, to promote large-scale interdisciplinary research projects. These projects often engage faculty, graduate students, and undergraduate research assistants on interdisciplinary cross-generational research teams to foster a pipeline of graduates and future faculty with interdisciplinary problem-solving skills and habits of mind.

39.6 New Developments in Interdisciplinary Teaching, Learning, and Assessment

Recent years have been rife with new developments in interdisciplinary teaching, learning, and assessment. Our understanding of interdisciplinary research collaborations and communications has expanded dramatically— providing useful models and explicit steps in the interdisciplinary research process that can be used to teach these processes to faculty and students. The science of team science is also contributing to understanding productive team interactions (Szostak 2013). O'Rourke et al. (2014) identify several models to enhance communications and problem solving by interdisciplinary teams, including (1) the Toolbox Workshop, used to provide multidisciplinary research teams with a framework for engaging in discussions about team dynamics and disciplinary research paradigms, and (2) concept mapping coupled with a dialogue process to help teams create integrated interdisciplinary frameworks to guide their research.

New learner-centered resources are now available to teach interdisciplinary problem solving. Repko's (2012) integrated research process identifies 10 steps, making the process explicit and transparent with discrete sequential tasks that support students new to interdisciplinary research. The steps in Repko's model align with the models proposed by interdisciplinary scholars, including Newell, Szostak, Haynes, and Augsburg, and suggest an emerging consensus about elements of interdisciplinary problem solving. The steps include:

1. Define the problem or state the research question.
2. Justify using an interdisciplinary approach.
3. Identify relevant disciplines.
4. Conduct the literature search.
5. Develop adequacy of each relevant discipline.
6. Analyze the problem and evaluate each insight or theory.
7. Identify conflicts between insights or theories and their sources.
8. Create common ground between concepts and theories.
9. Construct a more comprehensive understanding.
10. Reflect on, test, and communicate the understanding.

Repko also elaborates on strategies to achieve integration—often the most challenging dimension of interdisciplinary problem solving. These strategies include *redefinition*, in which the meanings of concepts are clarified; *theory extension or contraction* to accommodate other theories; *organization* to relate seemingly unrelated variables to the emerging framework; and/or *transformation*, in which opposing insights are placed on a continuum.

The model for interdisciplinary writing proposed by Boix Mansilla (this volume) aligns with the model developed by Haynes and Wolfe (Boix Mansilla et al. 2009) and provides criteria to teach and assess interdisciplinary writing, helping instructors design effective assignments and align their instruction with their goals and assessments. Like the Repko (2012) model, the criteria are clearly articulated and helpful for students new to this work. They include *purposefulness, disciplinary grounding, integration, and critical awareness*. For a full discussion, see Boix Mansilla, this volume.

Rubrics to teach and assess interdisciplinary learning have proliferated across higher education for a decade as a best practice in assessing student learning. Their use in assessing interdisciplinary learning was propelled by widespread adoption of the AAC&U Essential Learning Outcomes (2004) that include integrative and interdisciplinary learning outcomes and the development of rubrics to assess them. Specifically, the Valid Assessment of Learning in Undergraduate Education (VALUE) rubrics identify dimensions of integrative learning, including "the ability to make connections across disciplines" and "student reflection and self-assessment"—all relevant to interdisciplinary problem solving.

Worcester Polytechnic Institute's (WPI) Interdisciplinary and Global Division developed a rubric to assess its interdisciplinary student project requirement (Worchester Polytecnic Institute 2016). The VALUE rubrics and the WPI rubric reflect the trend in assessment to use rubrics to make expectations explicit, to teach, and to assess integrative and interdisciplinary learning.

Critical reflection and *metacognition* have long been central to interdisciplinary pedagogies as processes for learning and learning outcomes. Rubrics for interdisciplinary learning that specify these competencies reflect and promote their importance in interdisciplinary learning, encouraging instructors to integrate them with intentionality into teaching methods, assignments, and assessments.

There has been an exponential increase in the adoption of e-portfolios for assessment of learning. For example, the LaGuardia Community College Connect to Learning Project, with 22 participating institutions, was designed to use e-portfolios to assist students to integrate their learning across their collegiate experience, enable institutions to document attainment of student learning outcomes, and study the impact of e-portfolios on learning. The project findings emphasize the importance of intentionality and structure in e-portfolio development and the need to prompt and structure practice in reflection and integration to enable students to develop these habits of mind (Clark & Eynon 2011/2012). Similar to many interdisciplinary pedagogies, e-portfolios are effective when carefully designed with ongoing support to guide students as they develop integrative and metacognitive skills.

E-portfolios represent one of many technology-enabled online tools with implications for interdisciplinary teaching and learning. Digital pedagogies include widespread use of online learning management systems and digital tools that promote communication and collaboration among instructors, students, and external parties. Online collaborative writing tools have revolutionized collaborative writing. Digital tools used to create concept maps have enhanced their use by interdisciplinary teams. Increasingly, student assignments in interdisciplinary courses include the creation of websites and online archives, blogs, vlogs, wikis, and critiques of existing online resources. The emerging field of digital humanities now enables students to apply computational methods to research in the humanities, promoting cross-disciplinary and interdisciplinary research (Klein 2015). More broadly, computational tools are enabling students across the disciplines to access and use big data and to engage in cross-disciplinary borrowing of research methods to engage in interdisciplinary problem solving. These endeavors are generally collaborative and team-based, requiring interdisciplinary problem solving and integration.

Active learning continues to be a hallmark of interdisciplinary teaching and learning. There is increasing evidence of the use and effectiveness of the High Impact Practices (HIPs) in undergraduate education (Kinzie 2013; Kuh 2013) and new elaborations that integrate interdisciplinary learning. The HIPs include first -year experiences, learning communities, writing intensive courses, collaborative experiences, service learning, study abroad, undergraduate research, internships, and capstone courses. With these strategies too, impact studies affirm the importance of writing, critical reflection and metacognition to help students deepen their learning and to be more intentional, self-aware, and purposeful about integrative learning.

Institutions continue to experiment with multidisciplinary learning communities and their impact on students' understanding of how science works and the interconnections across science disciplines. One illustrative example of the scholarship of interdisciplinary teaching and learning (SoITL) within STEM was conducted by Luckie et al. (2013). Students co-enrolled in chemistry, biology, and history of science courses experienced one of three types of interdisciplinary experience, enabling their instructors to assess the impact of each model on their students' ability to make connections across the disciplines. In the low-dose model, students heard explicit cross-disciplinary references in their courses to concepts from the other disciplines and experienced periodic interdisciplinary exercises. In the medium-dose model, students in lab sections were assigned lab reports bridging the disciplines, hybrid lab groups of biology and chemistry students, or biology groups that were able to hire students from chemistry to collect data for them. In the high-dose model, students and faculty in all three courses met in a weekly discussion seminar to draw connections across the disciplines

The high-dose model had the greatest impact, transforming students' views and inculcating habits of mind to value and draw connections among these STEM disciplines. This SoITL project affirms that effective interdisciplinary learning requires explicit and sustained effort over time with recurring opportunities for students to identify and explore topics that bridge the disciplines. The presence of all disciplinary faculty in the discussions was important to the model's success. This type of SoITL research is making a valuable contribution to our understanding of interdisciplinary teaching and learning.

Graduate education is making its own advances with interdisciplinarity. Leaders in doctoral education are advocating for team supervision to reflect the shift toward more interdisciplinary research (Manathunga 2012). Gabrys and Beltechi (2012) make the case for interdisciplinary cognitive apprenticeship in doctoral education, relying on teams of supervisors from different disciplines to make visible the epistemologies of different disciplinary experts and how they work across the disciplines, in successive stages of modeling, scaffolding, coaching, and fading. Michigan State University offers graduate interdisciplinary teaching fellowships and instructs graduate students in how to obtain funding for interdisciplinary research as a new dimension of preparing future faculty.

There are new trends in interdisciplinary curricula, pedagogies, and learning spaces that cut across graduate and undergraduate education. These include interprofessional education in the health sciences to prepare graduates to work in cross-disciplinary teams of healthcare providers (see McMurtry et al., this volume). The digital humanities is an emerging discipline that applies computation to research in the humanities. Design labs are appearing across US research universities (Stanford University, MIT) and liberal arts colleges (Hamilton College, Occidental College). These labs enable teams of students with different disciplinary expertise to solve real-world problems (Klein 2015). Makerspaces provide physical environments to enable students across the disciplines to collaborate and innovate in technology-rich environments.

39.7 Conclusion

Several recurrent themes weave through these long-standing and new interdisciplinary pedagogies. Instructors need to be intentional in the design of interdisciplinary teaching and explicit in clarifying expectations for students to make appropriate use of disciplinary perspectives and to engage in the challenging process of integrating disciplinary perspectives to create robust interdisciplinary solutions. Writing and critical reflection are key features of the approaches to interdisciplinary teaching, learning, and assessment. Most approaches rely on team learning and the abilities to communicate and collaborate effectively. Technology is enabling new interdisciplinary pedagogies and access to interdisciplinary resources and data, enhanced communication and collaborative knowledge construction, and new research and computational methods that promote cross-disciplinary borrowing.

Implicit in these methods is the developmental nature of interdisciplinary learning over time, requiring practice at increasingly more challenging tasks to solve complex programs. Many students come to interdisciplinary work as novices in their discipline and experience a steep learning curve in the quest for interdisciplinary solutions to complex problems. This places special demands on instructors to provide a balance of clear and high expectations with high levels of academic and interpersonal support as students explore this new and daunting landscape.

Echoing the thesis of this chapter, Haynes (2002) concludes that there is no single, unique method associated with interdisciplinary teaching and learning:

> Interdisciplinary pedagogy ... is not synonymous with a single process, set of skills, method or technique. Instead, it is concerned primarily with fostering in students a sense of self-authorship and a situated, partial and perspectival notion of knowledge that they can use to respond to complex questions, issues and problems. . . . While it necessarily entails the cultivation of the many cognitive skills such as differentiating, reconciling, and synthesizing . . . , it also involves much more, including the promotion of students' interpersonal and intrapersonal learning. Because interdisciplinarity is a complicated psychological and cognitive process, it cannot be taught with one approach. (Haynes 2002, p. xvi)

Indeed, interdisciplinary teaching and learning requires a host of powerful pedagogies to inspire and enable teachers and students to grapple effectively with the complexity of problems we face in the twenty-first century. This work is challenging for students, but in many ways it is even more challenging for faculty who will be crossing borders and charting new terrain in higher education, leaving the relative safety of disciplinary expertise for the ambiguity of interdisciplinary real-world problem solving. Just as students benefit from peers to support them in this endeavor, it is equally important for faculty to have colleagues to share their wisdom of practice, their triumphs, and their challenges—recognizing that this is, as Haynes notes, a "complicated psychological and cognitive process" requiring creativity, commitment, and courage. In an era in which interdisciplinary teaching and learning continues to come into its own, interdisciplinary instructors no longer have to go it alone.

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CHAPTER 40

DOCTORAL STUDENT AND EARLY CAREER ACADEMIC PERSPECTIVES ON INTERDISCIPLINARITY

SARAH DOOLING, JESSICA K. GRAYBILL, AND VIVEK SHANDAS

40.1 Introduction

This chapter focuses on the experiences of graduate students and early career professionals who conduct interdisciplinary research and teaching. Interdisciplinarity has been heralded as an educational and research paradigm that effectively addresses complex problems at disciplinary boundaries (Tress et al., 2003; Weinghart & Stehr, 2001). However, few publications address graduate student and early career experiences in interdisciplinary research and training (IDRT) programs in traditional university settings. Published perspectives are largely those of well-established faculty or researchers, for whom it may be difficult to "understand and empathize with the ways students experience the institution. Faculty and staff tend to see the institution from their own perspective" (Hunt et al. 1992, p. 103). Guidance for doctoral students and early career faculty pursuing interdisciplinary academic trajectories in traditional university settings is emerging (Morse et al. 2007). However, despite the proven utility of investigating such perspectives to understand innovative pedagogy (Anderson et al. 2000), the experiences of doctoral students and junior faculty are rarely recognized by proponents for and administers responsible for IDRT programs.

Interdisciplinarity became a major focus of academics in the 1960s (Huutoniemi et al. 2010). Proponents proclaim that interdisciplinarity creates unique researchers and educators through innovative forms of communication and collaboration among disciplines. As noted in mission statements of universities and funding institutions, developing interdisciplinary research and education has become a lauded goal for many educational institutions. Often, interdisciplinary research and training (IDRT) programs are conceptualized and implemented by faculty interested in conducting cross-disciplinary research (considered a

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bottom-up approach; Jacobs & Frickel 2009), but these programs are also managed by faculty most entrenched in the structure and experience of traditional universities, colleges, and departments (considered a top-down approach; Jacobs & Frickel 2009).

While collaborative initiatives have typically occurred in the ranks of established senior scientists (Dubrow & Harris 2006), programs are now appearing earlier in academic careers, involving junior faculty in undergraduate and graduate education. As the increasing numbers of doctoral students trained in interdisciplinary approaches enter the academic workforce, their interdisciplinary experiences influence how or whether they decide to continue such work in their future careers. The challenges and opportunities encountered during doctoral training and in the transition to an academic career provoke questions about interdisciplinary research, training, and pedagogy within academia.

When heeded by faculty, departments, and universities, perspectives of doctoral students and junior faculty provide useful information for successfully creating and managing interdisciplinary programs. Whether universities are able to adequately support newly minted interdisciplinary scholars may determine the future success of interdisciplinarity as an academic enterprise.

Our chapter contributes to an emerging body of literature about "doing" interdisciplinarity (see Graybill et al. 2006). "Doing" interdisciplinarity refers to the formal and informal mechanisms that enable scholars from multiple disciplinary backgrounds and epistemological persuasions to engage in mutually beneficial and effective collaborations that may address a pressing societal challenge. We draw on existing literature and our own experiences to ground the pursuit of interdisciplinary research and pedagogy (IDRP)[1] by asking practical questions whose answers are intended to guide multiple participants (individuals, departments, institutions, disciplines) in cross-disciplinary endeavors. We address the benefits and challenges of participating in IDRP from the perspectives of doctoral students and early career academics, the latter defined as recently graduated PhDs in professorial academic positions.

Specifically, we address three topics. First, we identify the transitional stages of the interdisciplinary career, from doctoral student to early career academic. Second, we provide an account of the overarching concerns that arise for doctoral students and early career academics simultaneously pursuing disciplinary and interdisciplinary research and pedagogy in conventional university settings. We address the pursuit of IDRP at both public universities and private liberal arts colleges. Finally, we visualize potentially ideal IDRP institutions for newly minted interdisciplinarians. For each topic, we draw on the existing literature and our experiences to pose questions and suggest pragmatic strategies for promoting successful interdisciplinarity experiences. Each topic contains opportunities and challenges for students, faculty, and institutions. Every challenge must be addressed if interdisciplinary endeavors are to be successful in the long term. We conclude this chapter with a reflection on the increasing calls for interdisciplinary in the context of reduced funding for public universities and the rise of interdisciplinary programs at private liberal arts colleges.

[1] Interdisciplinary research and training (IDRT) and interdisciplinary research and pedagogy (IDRP) differ in meaning based on career stage. While IDRT describes the experiences of doctoral students who are being trained in interdisciplinary research and process, IDRP refers to those who have been trained in IDRT and who are pursuing careers in interdisciplinary research and pedagogy.

40.2 Transitional Stages

We identify four major transitional stages for doctoral students and early career academics trained in interdisciplinarity. After a definition and description of each stage, we pose questions aimed to promote reflection about IDRP across multiple institutional settings.

40.2.1 Initiation

Doctoral students being trained in interdisciplinary research must understand and meet expectations that are not necessarily integrated across intellectual communities, subject matter, or modes of conducting research (e.g., qualitative vs. quantitative approaches, empirical vs. theoretical foci, etc.). Interdisciplinary doctoral students are often asked to develop dual intellectual communities—disciplinary and interdisciplinary—simultaneously, while also balancing disciplinary and interdisciplinary expectations and becoming familiar with disparate knowledge bases. Students must develop multiple identities being part of disciplinary departments and interdisciplinary programs. Combined with establishing solid footing in disciplinary specific theories and traditions, and fulfilling expectations in disciplinary and interdisciplinary realms, these tasks can be exciting and liberating. However, this can also be a time of exhaustion and disorientation if an individual's grounding in disciplinary history and research is not solid before interdisciplinary efforts are attempted. Students grapple with the process of doing interdisciplinary research and are most fully immersed in the training aspect of becoming interdisciplinarians.

Questions raised during this stage include: Where do I situate my scholarship? What is my identity in my disciplinary department and interdisciplinary program, and are they (should they be) the same or different? How can I strategize to obtain maximum benefits from creating one or more research projects that must be undertaken simultaneously? How do I craft research project(s) so that (1) I may complete them in a timely manner and (2) they are rigorous and acceptable in both disciplinary and interdisciplinary realms?

40.2.2 Familiarization

Once initiated, familiarization occurs as students begin to create potentially dual research paths and disciplinary and interdisciplinary identities and learn to anticipate competing intellectual inputs, expectations, and reward mechanisms associated with disciplinary and interdisciplinary directions. Familiarization implies that students have successfully conducted interdisciplinary research, are fully immersed in the training aspects of it, and have grappled with many of the "nuts and bolts" issues of doing interdisciplinarity discussed at length elsewhere (Lélé & Norgaard 2005). These issues include learning/creating a common language, developing the professionalism needed for cross-disciplinary interaction, accommodating the extra time needed for team work, and practicing appreciative inquiry (learning to understand and value different kinds of scholarship).

Doctoral students become more able to navigate the dual loyalties to disciplinary and interdisciplinary intellectual communities, and have learned to juggle the demands of completing requirements in each intellectual realm (including interdisciplinary team research, individual disciplinary coursework, general exams, dissertation proposals and defenses, fieldwork, fellowships, and publications). Navigating these multiple requirements and expectations requires students to practice sophisticated negotiation techniques in order to define the scope of individual and team research possibilities. Navigation is a skill used by individual students with peers, faculty advisors, and potentially with departments, as the boundaries of feasible research must be identified and honored to maintain timely progress through the degree. For some students, funding becomes an important motivator for completion of their degree.

In the last phases of familiarization, doctoral students have become more comfortable with their dual identities in home departments and in interdisciplinary working groups as they near completion of all degree requirements. Outlets for publication outlets are identified, and academic career searches begin. Doctoral students, already familiar with the process of doing interdisciplinarity on a daily basis, must demonstrate in publications and to potential employers their breadth and depth acquired by dual accomplishment of disciplinary and interdisciplinary research and training. Further strategizing and negotiation may be involved, as students emphasize either disciplinary or interdisciplinary training, research, and potentially pedagogy, to potential employers based on the job descriptions and the priorities of institutions, disciplines, and individual departments. For interdisciplinary positions, especially for cluster hires or joint appointments, getting clarity about expectations for the tenure and promotion process and the allocation of teaching and research responsibilities across multiple academic units is important; incorporating these details into the offer package minimizes future confusion and conflicts. For disciplinary positions, the interdisciplinarian may identify potential interdisciplinary links, so being clear about intentions to pursue interdisciplinary inquiry is important.

Questions confronted during this stage include: How do I maintain rigor and depth in my disciplinary and interdisciplinary research, and still complete the PhD in a timely manner? What qualifies as legitimate levels and types (e.g., articles or books) of productivity and foci of research in my disciplinary and interdisciplinary fields? Where will I publish my interdisciplinary research, and how will the publication impact my hireability in a university setting (e.g., within or external to a discipline)? In a job interview, how do I describe the benefits and value of my interdisciplinary training to scholars entrenched in disciplinary knowledge bases? How do I explain or defend my IDRP interests in a discipline-oriented job talk? If applying for an explicitly defined interdisciplinary (or cluster-hire) position, how can I negotiate expectations for tenure and teaching across multiple departments?

40.2.3 Adaptation

Once placed in academic posts, newly minted interdisciplinary PhDs face new challenges and benefits. Most challenges derive from adapting to what interdisciplinarity means within different institutions, departments, and among new colleagues. While there is certainly excitement at being in a new institutional setting and exploring new collaborations for conducting IDRP, a sense of caution may also develop as new hires discover colleagues and institutions may have differing interpretations of—and value for—interdisciplinary research, training, and pedagogy. As Palmer (2001) states, interdisciplinarity is now essential to dialogues about knowledge production, yet "because the notion of interdisciplinary research has not solidified, debate about what it really means goes on" (p. ix). Recent attempts to delineate and describe the range of cross-disciplinary endeavors (e.g., Wagner et al. 2011; Huutoniemi et al. 2010) aid in solidifying understandings of multi-, inter-, and transdisciplinarity. But as increasing numbers of practitioners across disciplines and institutions continue to pursue cross-disciplinarity, the diversity of interpretations and practices also increases.

This is the milieu that early career academics trained in interdisciplinarity today find when they arrive in their first job postings in multiple kinds of institutional settings, from the liberal arts college to the public university. One formidable challenge facing the new hire in any setting is the reality that academics from different disciplines often only come together when (1) research proposals are formulated or (2) cross-disciplinary courses are taught. These networks are often robust, involving established faculty who are already familiar with each other's research or pedagogical modus operandi. Oftentimes, early career academics are often discouraged from such collaborations, for varied reasons (e.g., interdisciplinary collaboration seen as risky to obtaining promotion, quality/record of a junior faculty's work is unknown by established faculty, collegial relations are already established among certain departments/colleagues, etc.).

In the case of faculty collaboration driven by developing research proposals, persistent ties may not form as concern rests largely with obtaining funding. In the case of faculty co-teaching collaborations, the focus may only be on providing students with multiple viewpoints on a particular topic rather than faculty creating a shared understanding and agenda related to research and teaching interests. Without these deeper ties developing in either case, discussions about interdisciplinarity between researchers may remain limited, or may even become strained, as sufficient time for trust and social bonding has not been created.

Early career academics trained in IDRP can become particularly frustrated by these issues, because they already know the challenges of conducting IDRP (see stages 1 and 2 above), but must now weigh the benefits and challenges of pursuing it on top of institutional and departmental requirements. For some, this adds to the exhilaration of continuing to pursue dual career interests, and for others it is taxing, unrealistic, or even a disappointment with their individual institutional settings, which may lead to reduced motivation (personal or institutional) to continue with IDRP.

Questions confronted during this stage include: How much should I introduce and promote my vision for interdisciplinarity in my new institution and/or department? Does my institution consider interdisciplinary research or pedagogy risky in the tenure process, and what level of risk am I willing to assume as nontenured faculty? Should pedagogical techniques or collaborations that incorporate interdisciplinarity be introduced while I am in a pretenure phase? How will I manage the time commitments to building new IDRP collaborations, when my time is already apportioned by the university's preexisting expected research, teaching, and service commitments? How can I expand my network of interdisciplinary faculty on and off campus as sources of support and guidance?

40.2.4 Protected Enthusiasm

Within the first few years of working in traditional academic institutions, early career IDRP academics understand clearly what their institution requires for professional advancement. While enthusiasm for and commitment to the ideals of IDRP may remain, they may become protected or even diminished, as the individual must consider self-preservation within the institution in order to remain a viable candidate for tenure. Palmer (2001) attributes such cautionary practices to entrenched systems of rewards and promotion based on *individual* achievements and awards, resulting in "few concrete incentives" for academics to prove themselves outside their disciplines. Without incentives, academics "engender more potential risks than rewards" (p. 71) for pursuing cross-disciplinary, collaborative endeavors. After all, "there is a serious disaccord between what leads to a successful scientific project and what leads to advancement at a university" (p. 80).

The tenure and promotion system remains primarily based on the construct of division and competition among disciplines, and evaluation is about whether a pretenure academic has contributed to the scholarship within *a discipline*. The luxury afforded to IDRT doctoral students—the time and space to think creatively and collaboratively—is removed for early career academics who must become experts in their disciplinary fields in time-limited, promotional academic positions. For junior faculty hired with the expectation of bridging fields and disciplines, ambiguity about tenure criteria often persists. While the school or department most likely has clear criteria for tenure, upper-level administrators or discipline-based senior faculty involved in approving tenure typically are not informed about (or have not experienced) the specific challenges associated with IDRP, even if a university has approved interdisciplinary positions. For junior faculty hired for interdisciplinary positions, raising these questions during the third-year review is crucial for developing a well-informed strategy for the tenure process.

Early career interdisciplinarians may arrive at their new institutions unaware of pre-existing disciplinary divisiveness and of the protectionary mechanisms that exist for preserving the status and territory of disciplines. One author, excited at the possibility of new collaborations, sought interdisciplinary connections upon arriving on campus, but learned that other new discipline-oriented hires were apprehensive to take on new collaborations outside their fields prior to tenure due to high teaching loads and productivity expectations. Other challenges to cultivating interdisciplinary research teams involve perceptions among faculty about fields to which they have little exposure (e.g., social sciences are not "rigorous" or natural sciences are only concerned with narrow, laboratory-based learning and do not address the "larger picture", see Simon & Graybill 2010). Bringing together specific researchers/departments on an IDRP research project may be difficult, requiring more time than anticipated or even impossible given political and personality conflicts.

These issues could halt the best intentions of any individual seeking interdisciplinary research or pedagogical collaboration, but they may be particularly devastating to early career academics who are interested in jump-starting new collaborations in the early years of a tenure-track career. The reality sets in that some of these divides are best not battled in pretenure years. In response, early career academics may rely on existing, trusted connections to continue researching and publishing. These collaborations exist not only across disciplines, but also perhaps across different institutions scattered worldwide, which logistically may be very difficult.

Questions confronted during this stage include: How should I best represent my dual identity and my dual research agendas to internal and external reviewers for promotion purposes? Who are my potential external reviewers that are best able to understand my contributions to interdisciplinary research? What does my discipline/institution consider "risky" in the pretenure years (e.g., co-teaching across disciplines, conducting more interdisciplinary research than disciplinary research, publishing more coauthored interdisciplinary research than single-authored research)? How do I maintain enthusiasm for interdisciplinarity in my new institution when I may not be able to pursue it as I was trained as a doctoral student? Should I build interdisciplinary bridges within my institution, and maintain earlier collaboration networks? How can I, or should I, build meaningful interdisciplinary bridges in research, teaching, and service in my new institution right away? How can I use the third-year review process to strategize effectively about the tenure process? How can I seek to challenge or change my institution's views and practices of interdisciplinarity as an early career academic?

40.3 Overarching Concerns

While this handbook attests to the growing body of literature on "doing" interdisciplinarity, many colleges and universities claim that they have been conducting IDRP for several decades. What is different for doctoral students and early career academics now, however, is the fact that many institutions are only just acquiring newly minted PhDs formally trained in interdisciplinarity (coincident with the rise of large-scale, funded interdisciplinary programs nationwide, such as the National Science Foundation's Integrative Graduate Education and Research Traineeship (IGERT) Program). Formal training of interdisciplinary doctoral students still occurs largely by disciplinarians, although this is beginning to change with the appointments of cluster hires and other kinds of interdisciplinary positions. Currently, one primary challenge for institutions is to engage these newly minted interdisciplinary PhDs in ways that support their IDRT scholarship and pedagogy while also ensuring that traditional disciplinary-focused research continues.

The simultaneous pursuit of disciplinary and interdisciplinary research and pedagogy raises one major question for doctoral students and early career academics: *Are they performing for their disciplines, or for a new academy?* This provocative question raises the issue of where individuals want their work to have the greatest impact. Underlying this question is the recognition that the cultures of educational institutions directly impact IDRT efforts, and that most institutions have not yet been reconfigured to support and reward long-term IDRT and IDRP efforts. IDRT students and early career faculty must explicitly consider what level of risk they are willing to assume in developing their pedagogical and research agendas in light of their institutional context.

Also, IDRT and IDRP academics must continue to ask serious questions about the structuring of knowledge accumulation, learning processes, and promotional structures entrenched in higher educational institutions. Three major points related to these overarching concerns are discussed below.

40.3.1 Meaning of the Interdisciplinary PhD

One concern is what interdisciplinary training means in transitioning across academic career phases. Recognizing that a major challenge for IDRP is its on-going formulation—and variability—across different institutions and disciplines, early career academics must evaluate the level of risk associated with involvement in IDRP at different kinds of institutions (e.g., public versus private, research- versus teaching-oriented institutions). While innovative research advancement is more likely in settings that allow for early risk taking, safe-to-fail opportunities are common for many tenure-track academics (regardless of career stage). It is rare for any department to include risk taking as an explicit agenda in research or pedagogy (one exception is the promotion and tenure standards in the Department of Philosophy and Religion Studies at the University of North Texas). Activities, including consulting with public or private agencies, developing community-based pedagogy and research products, or developing new educational programs, do not result directly in typical scholarly outputs (e.g., grant awards, publications) and are not rewarded. We are not arguing that IDRP academics should not conduct these activities, but rather that early career interdisciplinarians are particularly vulnerable because of their formative training in problem-based, innovative research approaches and educational curricula.

This raises the issue of *clarity* related to interdisciplinarity. As increasing numbers of formally IDRP trained academics join the academic workforce, questions about how interdisciplinarity is defined and practiced (theoretically and practically), and who has "ownership" of it (e.g., those who have formal training in it versus those who have tried to design it without formal training) will increasingly emerge as central to "doing" interdisciplinarity. Related to clarity are the following questions: If academics in multiple stages of their careers are responding to calls for increased interdisciplinarity, how might we (1) value the many ideas about what interdisciplinarity is (see Huutoniemi et al. 2010, for a typology of interdisciplinary research), (2) understand if and where these ideas are being applied, and (3) learn how to sustain different kinds of interdisciplinary efforts? These questions speak to the need to continuously reflect on the various uses of the term, and to evaluate our individual, collaborative, and institutional IDRP practices.

40.3.2 Evaluation

Interdisciplinary doctoral students and early career academics are trained to evaluate and further knowledge, conduct research, and teach in new ways. How academics are evaluated, however, has not changed either in graduate school or in early career stages. The persistence of tenure and promotion practices raises the issue of how the existing systems of internal institutional and external evaluation might also be changed to make the pursuit of interdisciplinarity within largely traditional institutional settings holistic instead of dualistic (i.e., on top of existing performance requirements)? Addressing transdisciplinarity, Klein et al. (2001) write that such "projects should be evaluated in a different mode than disciplinary projects" (p. 16). The same can be argued for interdisciplinary projects, which also have what Klein and coauthors call a "special context of application, team process and participation [and] outcome and problem solving" (p. 17). Part of that special context is that interdisciplinary grants and projects are often undertaken to advance innovative research in new directions. Expected findings may be unknown ahead of time, and consensus among multiple reviewers on the purpose or merit of interdisciplinary grants and projects is difficult to obtain (Porter & Rossini 1985; see also Holbrook, this volume).

External peer evaluation of interdisciplinarity in grant-writing and publishing is also an overarching concern for graduate students and early career academics. Of particular concern are (1) what aspects of interdisciplinary research should be evaluated and (2) by whom. Which criteria commonly considered in the peer review of disciplinary research are sufficient for interdisciplinary research? Recent work proposes evaluation criteria for interdisciplinary scholarship that combines bibliometrics with measures of network dynamics to better capture the intellectual and social dynamics that lead to knowledge integration (Wagner et al. 2011). Which peer evaluators are qualified to judge disciplinary and interdisciplinary research? Russell (1983) argues that "criteria which acknowledge the unique qualities of interdisciplinary research" are necessary, including consideration of a research team's need to "maintain cooperation and communication towards a common goal" (p. 190). This may suggest that peer reviewers attuned to competition-driven grants and publications may not appreciate the structuring of interdisciplinary endeavors, and thus may not be suitable as reviewers of such research. With increasing numbers of interdisciplinarians seeking grants and new publication venues, this is a critical issue that deserves new attention today.

40.3.3 Institutional Adaptation

Interdisciplinary doctoral students and early career academics have been asked to become "agents of change" and to accommodate a "new academy" in their doctoral training, yet the institutions in which they function have largely not changed. A recent assessment of academic job postings listed through the *Chronicle of Higher Education* (during June to November 2007) revealed out of a total of 3,512 positions, only 6% described interdisciplinarity, with 25 positions listed at the junior rank (Borrego & Newswander 2011). Proportionately few of the appointments were within interdisciplinary centers or institutes, leading the authors to conclude that rigid disciplinary departmental structures still define the scope of faculty appointments, including interdisciplinary (Borrego & Newswander 2011) and cluster hires. How this mismatch will be addressed in the future is important to the success of interdisciplinarity in higher education. Institutional barriers include the existing awards and penalties system of tenure and the administrative allocation of teaching loads.

Accommodating interdisciplinarity could be done by identifying ways for faculty to "share" student course credit hours across divisions or colleges within one institution, establishing interdisciplinary centers/programs that assist in creating cross-disciplinary dialogue, recognizing and accommodating the time requirements for teaching interdisciplinary courses in addition to "required" courses, and assisting doctoral students and early career researchers in finding other new IDRT researchers on campus. In other words, good intentions to conduct (by doctoral students and early career academics) or encourage (by institutions) interdisciplinarity may not be enough for "doing" IDRT in higher education, and specific institutional strategies may be needed.

40.4 Interdisciplinary Futures: Strategizing for and Visualizing Success

A commitment to interdisciplinary training and research taken on by doctoral students and continued in further research and pedagogy by early career academics is admirable, as it is often conducted on top of existing requirements during the PhD or the pretenure years. Some authors have suggested that the commitment interdisciplinarians make to go "above and beyond" in research or pedagogy is done by a self-selecting kind of person or group (Cassell 1986; McCorcle 1982). Regardless of the type of person who may pursue IDRP in her career, a productive career in interdisciplinarity requires strategizing for success and, at the next level, visualizing what individuals, departments, and institutions need in order for IDRP to gain legitimacy and value. Below we briefly discuss a selection of individual strategies for success and propose some scenarios for visualizing success for individuals, departments, and institutions. This discussion and the scenarios are not exhaustive or conclusive; rather, they are meant to provoke responses and further thought from those most interested in the long-term success of interdisciplinary research and pedagogy.

Part of the process of bridging disciplines is recognizing the need to negotiate a "best" career path with oneself, one's department, and one's institution. This requires identifying strategies for *individual* success, which is counter to much collaborative, interdisciplinary research training. This means examining one's ethics and making choices about the pursuit of disciplinary or interdisciplinary endeavors and individual or team projects based on the prioritization of individual needs. Academics at these stages must decide what their balance of disciplinary and interdisciplinary research and pedagogy will be and how to maintain integrity in research and pedagogy in their individual disciplines while remaining "true" to interdisciplinary interests. Indeed, Palmer (2001) writes, "even the most interdisciplinary scientists have to make 'cold-blooded' decisions about how to concentrate their energy" (p. 82). Decision-making involves strategizing the routes for survival through internal (departments, institutions) and external (greater disciplinary) career pathways. Every individual trained in IDRP navigates things differently based on these three sites of knowledge and career production, largely in response to the tenure system of promotion fostered by their institutions.

A common concern that arises from strategizing is building and maintaining IDRP momentum when also asked to operate in the current tenure-track system of promotion and penalties. How individuals respond we consider "ethical strategies" for survival as interdisciplinarians retain integrity for themselves, while also sensitive to their colleagues, and to the project of interdisciplinarity. For many, this requires developing a "best path" to carve through the dissertation and early career academic phases. That best path may come across as disingenuous to one's identity as an interdisciplinarian or to the project of interdisciplinarity when individuals are forced to negotiate their research and pedagogical agendas to accommodate institutional policies and persistent disciplinarity. Such struggles are particularly poignant for pretenure faculty.

Table 40.1 visualizes the components of an ideal institution supportive of interdisciplinary doctoral students and early career academics. The scenarios depicted directly address the substantive issues that arise for individuals, departments, and institutions. We target

Table 40.1 Framework for Encouraging Institutional Support of Interdisciplinary Training, Research, and Pedagogy for Doctoral Students and Early Career Academics

Dimension of Support	Need	Selected Ideal Scenarios	Career Stage
Research	Opportunities for formal and informal interaction with scholars from multiple disciplines	• Create multiple cross-disciplinary forums for interaction: ∘ Research symposia ∘ Methodological workshops ∘ Social events ∘ Dedicated physical space to foster brainstorming	Doctoral students (with other IDRT students and faculty) Early career academic (with other early career and interdisciplinary faculty)
Pedagogy	Encouragement for innovative and interdisciplinary approaches to engage students in cross-disciplinary coursework	• Give faculty time to develop service- or inquiry-based courses (e.g., course releases for development of IDRP courses) • Provide institutional flexibility for cross-disciplinary classroom interactions (e.g., sharing course credit hours, listing courses across divisions) • Promote campuswide initiatives to practice appreciative inquiry of other disciplines in courses • Create topical seminars and workshops on interdisciplinary pedagogy	Early career academic
University/ institutional structures	• Opportunities to meet outside departments • Support for collaboration	• Fund IDRP centers that include research and pedagogical facilities • Create online networks to aid learning about and participating in cross-disciplinary research/pedagogy clusters • Provide workshops on "doing" interdisciplinarity and team research with external facilitators	Early career academic
Incentives	Explicit and effective rewards system for pursuing IDRT/P	• Develop language and guidelines in PhD programs to support IDRT students • Develop language and guidelines in tenure and promotion cases to support early career IDRP scholars • Create institutional or departmental mission statements and goals regarding disciplinary and interdisciplinary research and pedagogy • Fund internal grants for promoting team-based, cross-disciplinary efforts	Doctoral student Early career academic
Evaluation	• Recognition of contributions made outside disciplines (e.g., interdisciplinary journals, governmental and professional reports) • Recognition of interdisciplinary teaching that draws together students with diverse disciplinary backgrounds • Space for students and faculty to express needs to administrations	• Reward disciplinary and interdisciplinary contributions to scholarship • Promote enrollment of students from multiple disciplines in disciplinary courses • Evaluate the process *and* product related to efforts to conduct research with members of other disciplines (e.g., recognize the time and "leeway" for IDRP efforts to succeed) • Instill adaptive management of IRDP in the administration as a mode for faculty to actively engage with institutional structures	Doctoral student Early career academic

solutions for the needs of interdisciplinary doctoral students and early career academics so that they may thrive in the sustained rise of this new paradigm.

Ideal conditions must now be evaluated in light of the economic difficulties resulting from the 2008 recession, which has significantly impacted the budgets in public institutions of higher education, as state legislatures allocated far fewer funds. Private colleges have also suffered from diminishing endowments and reductions in private donations. The National Science Foundation's IGERT program was reconfigured in 2014 as the Research Traineeship Program, effectively removing interdisciplinarity as the main focus. This national shift of funding options for universities coincides with universities rewarding departments that generate larger student credit hours. Disciplinary administrators are now attempting to reduce "leakage" of student credit hours, by sometimes requiring students to increase the number of courses taken in a single department. The private sector is now in a stronger position to fund interdisciplinary research, since it is more tolerant of risk and understands the commercial value of some research projects. A recent assessment of NSF IGERT graduates found that 69% considered at least two employment sectors (academy, private, government; Carney et al. 2011).

Meanwhile, calls for IDRP seem to be gaining momentum. Research centers, including the NSF-funded National Socio-Environmental Synthesis Center (http://www.sesync.org/about/programs) are becoming increasingly important in funding IDRP. As universities struggle with deep budget cuts, and faculty juggle high and sometimes increasing teaching and administrative duties, creating supportive conditions for IDRT becomes even more necessary and more difficult. Younger generations of interdisciplinarians are now faced with the task of revising the idea of the University in light of political-economic changes, while also continuing to create creative and productive ways of fostering IDRP.

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CHAPTER 41

FACILITATING INTERDISCIPLINARY SCHOLARS

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As innovation increasingly occurs at the boundaries of disciplines, scholarship is breaking out of the "discipline within a department" structure, posing institutional challenges for interdisciplinary scholars. The editors at *Nature* (2015) note, "To solve the grand challenges facing society—energy, water, climate, food, health—scientists and social scientists must work together. But research that transcends conventional academic boundaries is harder to fund, do, review, and publish—and those who attempt it struggle for recognition and advancement" (p. 305). Millar (2011) reflects this view as well, "analyses suggest there is potential for interdisciplinary research to disadvantage those who conduct it. Employers who are interested in expanding interdisciplinary research must recognize this potential and ensure that they do not create obstacles for interdisciplinary scholars. Funding agencies that are looking to support interdisciplinary projects should recognize that promoting this type of research may affect the individuals who pursue it" (p. 194). Traditionally, power, money, hiring, and promotion are allocated by departments. As graduate departments train and produce the next generation of scholars, departments hire graduates from similar departments, creating a powerful means to sustain the existing structure. This structure poses barriers to interdisciplinarity at every turn—in the universities' organizational design, lack of motivation within the institutional power structure, impediments to academic career advance, and the lack of institutional incentives.

Klein and Schneider (2009) note that while interdisciplinary research is connected to cutting-edge integrative work, the sustainability of interdisciplinarity within university structures is highly variable, with campus culture creating impediments to continuation. These barriers lead to difficulties in managing the complexity of interdisciplinary relations—the transaction costs—both within and outside of the institution. Even students feel the strain when they undertake interdisciplinary programs of study and find themselves being taught and advised by faculty on loan from other departments, unstable course offerings leading to difficulty in completing requirements, and a lack of advisors, facilities, community, and information on potential career trajectories.

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At a time when interdisciplinary scholarship is being asked to address critical human problems (cf. Committee on Facilitating Interdisciplinary Research 2004), interdisciplinary researchers face challenges beyond that of the research question. This chapter reviews the dynamics of interdisciplinary scholars functioning within a disciplinary tradition and provides guidance for better support mechanisms to facilitate interdisciplinary scholarship.

41.1 Approaches to Interdisciplinarity

A variety of issues are conflated in the pursuit of interdisciplinary scholarship and teaching (Table 41.1). These issues stress interdisciplinary scholars as they attempt to work within the traditional disciplinary framework. Many interdisciplinary endeavors are in new fields, requiring the establishment of new scholarly communities, with new resource needs (e.g., the need for shared space or additional travel) and new relationship demands (e.g., the need to learn a shared language). Interdisciplinary research and education is often collaborative, using informal, ad hoc teams (Evaluation Associates 1999; Lattuca 2001). Informal arrangements result in questions about credit for leadership and challenges in negotiating group interactions. Assessment of an individual's contribution (crucial for promotion and tenure) is also problematic in that interdisciplinary scholars tend not to specialize (Porter et al. 2007). And researchers who do not specialize pay a productivity penalty (Leahey et al. 2008), because coming up to speed in new fields and setting up new collaborations slow down publication rates. An additional complication is that members of groups underrepresented in the academic elite (women and perhaps minorities) appear to be disproportionately drawn to interdisciplinary research and education (Rhoten & Pfirman 2007).

However, not all interdisciplinary research is collaborative, nor is it all applied. As Rhoten and Pfirman (2007) point out, there are many ways to be interdisciplinary (Figure 41.1). One can approach interdisciplinarity at a variety of scales, ranging from intrapersonal—where an individual tackles research from multiple perspectives; to the interpersonal—working with others; to the interfield and intercommunity—working with nonacademic stakeholders, for example business and policy makers. Interdisciplinary teaching ranges through the same categories, each with their own set of administrative issues: the need for course release to develop the intrapersonal expertise, coteaching credit for the interpersonal approach, departmental buy-in for the interfield class, and adjunct support for practitioners when external stakeholders are involved.

What this means in practice, for the establishment and fostering of interdisciplinary scholars, is that they are dealing with many issues at the same time. They are tackling interesting problems using new approaches working with nontraditional audiences, often outside of academia as well as outside of one discipline. At the same time that they are gathering their own individual expertise and gaining recognition for their creative contributions, they also need to justify both their field and their approach (Langfeldt 2006), even within small interdisciplinary research teams:

> Each of us has had the experience of feeling as though we do not "really" belong to the research team, or that, upon returning to our scholarly "homes" after a research meeting, we do not really belong there either. Working at the boundaries of communities of practice, team

Table 41.1 Positive and Negative aspects of Conducting Interdisciplinary Research (1) and Education (2) are Disproportionately Skewed toward Positive in the Early Stages, Followed by Negative at Later Stages

(1) Interdisciplinary Research		
	Often early attraction. . .	But later difficulties. . .
New area	Can break new ground Less competition Less urgency	Less recognition by established scholars Fewer sustained funding opportunities Fewer journals Fewer peer reviewers Career trajectory not known Long start-up time
Social/applied connections	Appeals to social conscience Connect with public good	Less prestigious research area Considered less rigorous
Complex questions	Holistic approach required	Considered less rigorous
Collaborative	Build on strengths of others Use people skills	Time to cultivate and maintain Critical literature in other field Dependent on collaborator Idea origin not clear
Between depts/centers	Freedom because outside of established hierarchy	Less administrative support
Interinstitutional	Broadens network for letter writers	Requires travel Less visibility on home campus
(2) Interdisciplinary Education and Community		
	Often early attraction . . .	But later difficulties . . .
Teaching	Exciting subject Student interest Coteaching Field experiences Service learning Engaged practitioners	Fewer textbooks, resources Less infrastructure and fewer rewards to sustain "extra" activities (field, service) Coteaching Heavier student advising load
Campus life	Campus programming Community connections Bridge between disciplines: search committees, presentations Become known on campus	More service and outreach expectations
Scholarly participation	Field more open, can initiate programs	Fewer high-level, prestigious committees Fewer honors than in disciplinary fields
Promotion and tenure		Criteria often disadvantage interdisciplinary scholars

(adapted from Pfirman et al. 2011).

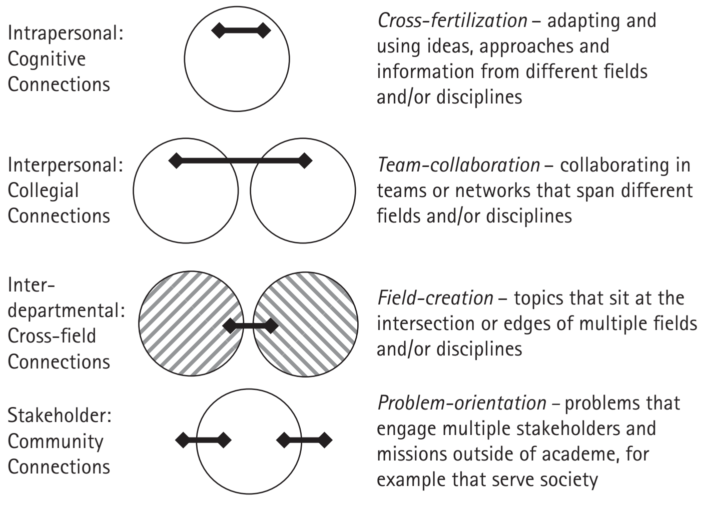

FIGURE 41.1 Interdisciplinary ways of conducting research and teaching

Pfirman et al. 2011; based on Rhoten & Pfirman 2007.

> members can feel uprooted, alien, frustrated. . . . When data from one's discipline is under scrutiny in an analysis session, the insider may perceive a need to defend her turf, provoking a sense of resentment and conflict with the rest of the team. (Lingard et al. 2007, p. 506)

Klein (2008) identified the challenge of peer review for interdisciplinary research, as conflicting assumptions about quality affect evaluation outcomes along the continuum from grant proposal evaluations to research performance and outcome determination. Add to this a potential bias and limitation of traditional bibliometric methods for interdisciplinary research assessment (Rafols et al. 2012; Porter & Rafols 2009; see also Holbrook, this volume). Spanner (2001) found that most interdisciplinary scholars believed that they operated in a more complex environment than disciplinary scholars, and many thought that they needed to know more information—with significant problems in locating useful information scattered across diverse fields (see Palmer, this volume).

Coteaching an interdisciplinary course raises similar issues in the classroom, as faculty feel compelled to justify their teaching methods and content selection. These continued self-examinations and appeals for acceptance can lead to a sense of personal vulnerability, tension, insecurity, and demoralization. Many believe they must continually declare, and be modest about, their limited knowledge of other fields in which they are working, or they risk being considered as "dilettantes who knew too little and claimed too much" (Lattuca 2001, p.3). As scholars move away from a disciplinary base into interdisciplinary endeavors, they often report that they no longer fit in as well as they once did: While their peers establish identity and status within the discipline, interdisciplinary scholars have "to live without the comfort of expertise" (Lattuca 2001, p. 133).

It is therefore not surprising that the University of Wisconsin's Women in Science and Engineering Leadership Institute (WISELI) found the critical determining factor in the quality of workplace interactions (including informal departmental interactions, colleagues' valuation of research, isolation and "fit," and departmental decision-making) was whether or not individuals thought their colleagues considered their research to be "mainstream" (WISELI 2003).

Despite these challenges to personal identity, many scholars are determined to follow interdisciplinary research and teaching agendas, even when they are not in supportive environments. In the analysis of UK researchers by Evaluation Associates (1999), 30% of highly interdisciplinary scholars were based at institutions where they rated the "overall environment in your institution for interdisciplinary research worse than that for single disciplinary research" (p. 53). For others it is a choice between interdisciplinarity or something else completely: As Kinzig commented in Haag (2006), "I think we have an increasing number of students who aren't that interested in being disciplinary. I think if I had had to focus narrowly within a particular discipline, I would not have finished graduate school. I just would have gotten bored" (p. 267).

Early career interdisciplinary scholars are especially affected by issues of academic community, evaluation, and administrative responsibility. When they first embark on interdisciplinary research and education, they are buoyed by excitement and see mainly the positive aspects of venturing into new territory (Table 41.1). By breaking new ground, they are able to set themselves apart from others, have a lot of autonomy in their research agenda, and can work with colleagues from a variety of disciplines and communities. But then, as they continue their scholarship, often moving toward tenure consideration, the negatives become more and more problematic, and many of the conflated issues (Table 41.2) raise difficult challenges. Bryne (2014) said, "There's a certain irony in government and vice-chancellors championing this [interdisciplinary] approach and funding the best graduates with competitive

Table 41.2 Characteristics Often Associated—and Conflated—with Disciplinary and Interdisciplinary Research and Education

Disciplinary	⇔	Interdisciplinary
Departmental	⇔	Interdepartmental
Mainstream	⇔	Nonmainstream (WISELI 2003)
Specialized	⇔	Diverse (Leahey et al. 2008)
Discovery	⇔	Integration, application (Boyer 1990)
Specialization	⇔	Integration (Porter et al. 2007)
Laser	⇔	Searchlight (Gardner 2007)
Disciplinary	⇔	Synthesis
Basic	⇔	Applied
Hierarchical	⇔	Collaborative, democratic
Formal	⇔	Informal (Lattuca 2001)
Established	⇔	New ("fringe") (Spanner 2001)
Majority	⇔	Minority (Rhoten & Pfirman 2007)

interdisciplinary studentships and fellowships, while not changing the conventions that make it so difficult for those who choose this route early in their careers to actually progress."

It is harder to publish interdisciplinary research in traditional journals well known by the disciplines. Collaborative projects take a long time to get up and running due to their high transaction costs. Consistent guidelines or processes for evaluation of interdisciplinary research are often lacking or require identifying particular experts for the particular research agenda (Klein 2008). Additionally, if scholars have joint appointments or affiliations with more than one department, they may be getting conflicting advice (or none at all) on how best to demonstrate their research contributions.

Similar issues arise from the perspectives of education, community participation, and service (Table 41.1). Given these challenges, early career scholars are often wary—or warned off—of embarking on interdisciplinarity. Mentors, champions, and role models are often helpful in easing the personal anxieties of early career scholars at the same time that they provide professional guidance and support. But navigating the complexities as individuals is challenging for scholars at all stages of their careers. The best is when institutions realize that they have a responsibility to address these issues.

41.2 Institutional Support for Interdisciplinary Scholars

Institutions are recognizing that departmental structures create barriers for scholars working between departments and are adjusting to the needs of interdisciplinary scholars (Table 41.3).

While most institutions have now made at least modest efforts to include interdisciplinary educational programs through establishment of minor courses of study, many

Table 41.3 Spectrum of Institutional Interdisciplinary Commitment, Investment, and Therefore Also Responsibility

Commitment and Investment	Modest	Intermediate	Significant
Students and curriculum	Minor. General education elective	Concentration. Special major	Major. General education requirement
Administration	Committee	Center. Program	Interdisciplinary department. Dissolution of departments
Faculty	Affiliated hire in disciplinary department. Adjunct hire	Off-ladder. Joint hire	Tenure-track interdisciplinary appointment
Research scientists	Soft-money support for single or short-term project	Multiyear support	Institution-committed career interdisciplinary research scientist line

(adapted from Pfirman et al. 2011).

others have established interdisciplinary centers and programs, created interdisciplinary departments, and hired senior interdisciplinary scholars. Some have gone as far as breaking down the disciplinary departmental structure altogether (Collins 2002; Feller 2002).

Institutions may create an overlying interdisciplinary framework to provide administrative structures that expand and nurture interdisciplinary collaboration. One example can be seen at Wesleyan University College of the Environment, where students and faculty are supported and linked in a think-tank design that overlays other university units (Poulos et al. 2012). The greatest stress seems to occur at intermediate levels of investment as institutions and individuals attempt to adjust to the needs of interdisciplinary scholars. Because their needs are novel, the scholars often fall between the cracks of administrative responsibility (Figure 41.2).

Being intentional about supporting interdisciplinary scholars requires thinking through the potential challenges in advance. The individual should not be put in the position of having to create their own process at the same time as they are attempting to navigate it. Creating an awareness of differences between interdisciplinary and disciplinary experiences—as we discuss below—can be helpful, from structuring a new hire, to understanding issues related to productivity, teaching, recognition, and evaluation. Awareness, however, is not enough. Funding and administrative support must also be provided. It is critical that institutions make commitments at the level of provost, vice president for research, or dean to the implementation and advancement—not just to the initiation—of interdisciplinarity (Feller 2002).

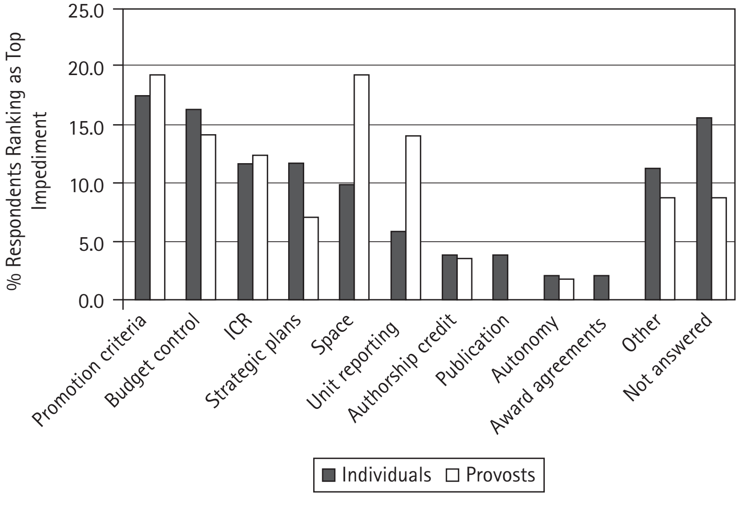

FIGURE 41.2 Impediments to interdisciplinary research identified by individuals and provosts in response to a request to rank the top five impediments to interdisciplinary research at their institutions (Committee on Facilitating Interdisciplinary Research 2004). Note the high ranking of promotional criteria as well as structural/administrative concerns: budget, indirect costs, space, and unit reporting. ICR = indirect cost recovery.

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41.3 Structuring an Interdisciplinary Hire

The process of creating a new interdisciplinary position and the negotiation of the hire often determines the administrative framework of a position, and it is this framework that needs special attention for interdisciplinary scholars. Decisions about new interdisciplinary positions require more extensive cross-institutional preparation than traditional disciplinary hires. At the start of position creation, roles and expectations must be clarified and agreed on by all the departments and academic administrators involved, ideally including representatives of promotion and tenure committees, and those responsible for allocating facilities and resources (Pfirman et al. 2011).

While joint appointments (department–department or department–center) appear to make sense for interdisciplinary scholars, such appointments often lead to difficulties. One is the expectation for service, an expectation that is often double for the joint appointment, serving the needs of two entities—or being penalized for appearing not to serve—for example when teaching is bought out by a research center. Joint appointments may be held to the tenure standards of both departments, which may be at odds (e.g., publications in journals versus books, sole versus multiple authorship). Because responsibility for joint hires is divided, the early career scholar may not get the guidance that they would within a disciplinary department or even through a professional association (Table 41.1). The annual meeting of a discipline's professional association is the place to give presentations, test ideas, and meet the leaders in the field. Interdisciplinary scholars often contribute at the fringe of disciplinary meetings, or risk limited mainstream visibility when they participate mainly in smaller workshops closer to their field of endeavor.

When interdisciplinary faculty are joint hires, it becomes imperative that each department manages their expectations, so that the time and activity demands on the joint appointment are reasonable and not doubled. Having a departmental split of 60:40 or 70:30 may be preferable over a 50:50 split to provide immediate clarity about departmental service (Pfirman et al. 2011). For early career faculty, an even better arrangement might be an "affiliated hire," where they are clearly based in one department but have specific research and teaching contributions to another department, program, or center.

For all interdisciplinary hires, but especially for those who hold joint appointments between departments, the scope of the position should be articulated in a memorandum of understanding (MOU) that spells out scholarship expectations, promotion criteria, teaching responsibilities, departmental and community service, budget, indirect costs, graduate student/technician support, and space (Table 41.1, Figure 41.2). These overarching expectations can then be shared with potential candidates, and later adjusted as part of the negotiation package for the new hire. Interdisciplinary teaching expectations need particular attention. Coteaching classes with scholars from other departments can result in difficult negotiations with the administration and each department about course load, credit, responsibility, content, and pedagogical approaches.

Many interdisciplinary educational goals would be best served by student-centered pedagogy—taking students out into the field, interacting with stakeholders, getting involved in civic engagement, or conducting student-led research. While these types of programs are often cited by students as transformative educational experiences, they are generally considered by the administration to be optional for faculty where the academic program has traditionally been delivered through in-class lectures and structured laboratories. Faculty who choose to incorporate these aspects in their teaching therefore do so at the expense of time they could spend on research, and may even risk having their teaching considered "soft" or "not rigorous" in comparison with colleagues who use more traditional approaches. An interdisciplinary faculty pedagogy forum, joint with schools or departments of education, can be designed to foster sharing of best practices, as well as an increased awareness of the value of new educational approaches and challenges faced within different disciplines. It can also open up education as an area of common ground, building ties between disciplinary and interdisciplinary academic professionals.

An institutional structure that can work well for interdisciplinary hires is a cluster hire (Sá 2008) to support a general theme or initiative, such as environmental sustainability. The administration, relevant departments, and centers work to create the cluster, setting the stage for broad acceptance of the theme. Departments can compete to be the home department of the new hires, thereby creating greater departmental acceptance of the interdisciplinary scholar.

41.4 Productivity and the Interdisciplinary Scholar

One of the most critical aspects to the success for any scholar is their research productivity: the number of publications is often the factor first reviewed for faculty hires and candidates for tenure. Interdisciplinary scholars face hurdles in being productive beyond those of other researchers for a variety of reasons: the field may be new and the scholarly community not yet established, collaborative research requires high overhead/transaction costs in terms of communication, administration (Tables 41.1 and 41.2; Collins 2002; Sá 2008), and additional training requirements. Moreover, each discipline has its own convention for writing grants and publications, and disciplinary-based reviewers often raise issues and request revisions inappropriate for the scope of the interdisciplinary project or difficult to reconcile because they are at odds.

An interdisciplinary scholar can deal with this situation by building expertise in their particular interdisciplinary area—effectively specializing in that area—and then branching into related research topics and publishing in related journals. Researchers in sociology and linguistics who specialized (had a more limited set of key words associated with their publications) were twice as productive as researchers who pursued a research agenda that changed fields substantially over the course of their career trajectory (Leahey et al. 2008).

Although early career researchers in any field are often admonished not to "spread themselves too thin" this advice might be especially important for interdisciplinary scholars. Research by Porter et al. (2007) indicates that scholars who are highly integrative tend not to specialize. It may be that people with a "synthesizing mind" (Gardner 2007, p. 3) use integration as part of their methodology, just as a lab scientist may address research problems using similar instrumentation throughout their career. Spanner (2001) also found that interdisciplinary researchers—especially those at the junior level—were fluid in that they often deviated from their research agenda as they received input from another field.

Börner (2006) has tracked intersections among the disciplines by mapping knowledge domains—in the process creating a communication tool. Interdisciplinary scholars can use this approach to work through related communities in linked networks, expanding their connections and therefore spreading their professional recognition. Mapped knowledge domains not only connect scholarly communities but also can act as another measure of interdisciplinary productivity (Palmer, this volume).

41.5 Recognition of the Interdisciplinary Scholar

Along with productivity, assessment of research performance relies on community reputation, especially recognition for creativity and achievement. Recognition arises from scholars reading and discussing each other's work. Scholars who have achieved recognition serve as informal field gatekeepers, assessing whether a new idea or product should be included in the domain. It is much easier for gatekeepers to recognize innovation when the advance is a direct extension of their own work or that of known colleagues. The difficulty of doing so is compounded by publication in new, interdisciplinary journals with nascent reputations. Without a process and a community for achieving recognition for creativity, the interdisciplinary scholar is faced with significant hurdles in promotion and tenure as well as in funding.

One way to create an interdisciplinary culture on campus, as well as to raise the profile of specific interdisciplinary scholars, is for interdisciplinary scholars to invite leading researchers to give presentations locally. This allows the local scholar to be the host: they get to know the external speaker better, they have the opportunity to talk about their own research, and issues of common interest become something known and talked about on campus. Such interactions are useful for any early career scholar, but are particularly important for those who are interdisciplinary or are in emerging fields. It is helpful in gaining trust if departmental members get a chance to meet prominent interdisciplinary experts firsthand.

While our focus thus far has been mainly on early career interdisciplinary scholars, senior scholars also experience recognition challenges (Pfirman et al. 2011). Most disciplinary societies have something along the lines of a "lifetime achievement award" that identifies major accomplishments and gives credit for accumulated success. In emerging interdisciplinary areas, the scholarly community structures, and therefore the opportunities for recognition, are not well formed. Also, if the interdisciplinary scholar has not specialized, their contributions may be spread over a number of different communities and therefore may not rise to the level of an award in any one of them. Less likely to be the targets of recruitment from other institutions, interdisciplinary scholars may not get the offers that stars do within the disciplines. It is essential that institutions recognize these fundamental differences, and that they support their interdisciplinary scholars—perhaps through the establishment of institutional awards and medals that recognize their overall impact.

41.6 Interdisciplinary Evaluation and Promotion

Conventional, disciplinary-based procedures and standards to assess the work of interdisciplinary scholars ignore the real asymmetries between disciplinary and interdisciplinary research and teaching. In the 2004 Committee on Facilitating Interdisciplinary Research study, concern about "promotion criteria" was the most frequent issue raised by both individuals and provosts in response to a request to rank the top five impediments to interdisciplinary research at their institutions. Mismatched metrics include the number of publications (as noted above, interdisciplinary, multiauthored work often has a slower production rate), focus on single- or first-authored papers (interdisciplinary publication often involves multiple authors), prioritizing well-known, disciplinary journals (not always an outlet for interdisciplinary scholarship), and citation indexes (interdisciplinary research is often new and must build its own constituency).

While tacit knowledge including unwritten guidelines for tenure within a department are passed along through informal collegial interactions and following the outcomes of individual cases, the interdisciplinary scholar is commonly the test case that establishes the criteria through their own performance. But it is not their responsibility to do so—institutions that hire interdisciplinary scholars should create appropriate procedures and metrics, and then be clear about expectations. A compelling way to address this situation is to change how scholarship is evaluated. Boix Mansilla (2006) noted that interdisciplinary work can be viewed through the lens of "consistency with multiple disciplinary antecedents, *balance* of disciplinary perspectives in relation to research goals, and *effectiveness* in advancing knowledge through disciplinary interventions" (p. 18). Lattuca (2001) recommends judging all scholarship simply "on the basis of its contribution to the advancement of knowledge" (p. 266).

Another option is to shift from using only "discovery" as the critical component, to the use of Boyer's (1990) expanded set of criteria: "discovery," "integration," "application," and "teaching." Individuals can be asked to provide information on their contributions in each of these areas in their annual performance reports and then the same categories can be used in tenure review. The University of Southern California, Duke University, the University of Michigan Medical School, along with some small liberal arts colleges and some large US land grant universities do this now. However, a word of caution: one study of applied health researchers found that even when interdisciplinarity is at the core of an institution's mission, the chairs of promotion committees, and to a lesser extent the deans, tend to accord significantly more value to traditional scholarly outputs, ranking the importance of nontraditional research output at or below the level of teaching (Phaneuf et al. 2007). Similarly, van Rijnsoever and Hessels (2011) found "that both in basic and strategic disciplines, disciplinary research collaboration is positively related to academic rank, but interdisciplinary research collaboration is unrelated to academic rank" (p. 469).

Reviews of interdisciplinary scholars and proposals can also be facilitated by providing institutional clarity in terms of overall staffing/budget priorities and helping evaluators understand their mission. Letter writers, reviewers, and evaluation committees can be alerted that the scholar or request for proposals is interdisciplinary, and then be provided with the original position or program description. Other options are to collect input from more areas of expertise, permit proposers to provide input on reviewer selection, and allow for proposer response to initial reviews (Langfeldt 2006).

In the case of a tenure review, the make-up of the review committee itself can be critical; it is frequently helpful to include an external expert in the field of the candidate. A problem that can arise, particularly with new areas of interdisciplinary endeavor, is that the outside expert may not be a senior scholar, and therefore may not carry the same professional capital that the external member typically wields in this situation. In order that the review does not depend on this one scholar, individuals can also provide an annotated curriculum vitae, detailing their specific contributions to coauthored publications and grants, cotaught classes, informal advising, and standing of journals/publications—venues that may not be known to members of the committee (Pfirman et al., 2011).

41.7 Funding for Interdisciplinary Research and Education

Traditionally, funding sources, whether internal or external to the university, have been channeled through disciplines. Therefore, support for interdisciplinary research and education is less stable than that for the disciplines. When interdisciplinary proposal calls are issued, they often have incredible competition, typically resulting in funding rates of less than 10%. Then, within 5 years or so, the funding area is often discontinued or moved to another administrative structure. The National Science Foundation, after a period of attention toward an interdisciplinary area, frequently attempts to migrate support back into the core disciplinary directorates, with the goal of changing the culture in the directorates, as well as allowing for new areas of focused attention at the cross-directorate level. However, because of disciplinary pressure, the emerging interdisciplinary areas may not be continued, especially under conditions of budgetary stress.

As a result, interdisciplinary scholars lack continuity in programs and program managers to go to for support. When responsibility for the program shifts, interdisciplinary researchers must establish new contacts, spending considerable effort in rebuilding professional capital. Committing to long-term support—effectively mainstreaming—interdisciplinary programs is essential. Funding agencies and donors can also support research on the reform of faculty reward systems and invest in research on ways to evaluate and facilitate interdisciplinarity.

Funders and institutions can help support interdisciplinary scholars by recognizing that as they initiate interdisciplinary activities, the individual will move "out on the limb" with their infrastructure lagging behind their needs (Collins 2002, p. 81). They can be provided with release time, co-funding, matching funds, and other support for crafting and implementing complex or major research proposals, as well as new interdisciplinary or cotaught classes. Investing and promoting a small number of high-profile projects likely to have success can help institutions develop models that will then reduce resistance to tackling more risky endeavors.

Another major need in terms of funding is to explicitly support all four approaches to interdisciplinarity: intrapersonal, interpersonal/collaborative, interfield/interdepartmental, and working with external stakeholders. The scholar wishing to develop intrapersonal expertise will need seed funding, sabbatical time, and course release as well as perhaps travel support to learn from other institutions, along the lines of the Andrew W. Mellon Foundation "New Directions" grants. Institutions can also provide proposal preparation support: increasingly, requests for proposals are requiring representation from multiple areas of expertise, which often is translated into large collaborative proposals. While both funding agencies and reviewers tend to assume that partnering with multiple institutions always enhances integrative research, for long-term sustainability of research programs it is sometimes better to invest in growing local expertise (Cummings & Kiesler, 2005).

Support is also required to develop opportunities for collegial contact, both professional and social: time and space is needed for collaboration to occur. Co-funding of research centers is one way many institutions are supporting interdisciplinarity. But funding for informal interactions is also helpful. As noted above, most interdisciplinary research is conducted in ad hoc, rather than formal, research teams (Evaluation Associates 1999). Similarly, 91% of the interdisciplinary scholars in the 2001 Spanner study rated collegial contact as being very important for their work. In addition to serendipitous connections, institutions can build trust through shared experiences such as social occasions and field trips, as well as through the more usual academic paths such as seminar series and workshops. Managing teams is difficult, but managing ad hoc interdisciplinary teams is even more challenging, due to issues conflated with interdisciplinarity (Table 41.2). Explicitly training interdisciplinary scholars in team management could lessen stress and increase effectiveness.

Interdepartmental and interinstitutional initiatives face major hurdles in negotiating terms of budgets, indirect cost recovery, and space. In fact, the Committee on Facilitating Interdisciplinary Research (2004) found that, after promotion criteria, these are the most critical issues faced by interdisciplinary scholars (Figure 41.2). Having a particular person within the institution's administrative structure whose job it is to sort out these issues greatly reduces the transaction costs of initiating new projects.

41.8 Conclusion

Clearly, institutions serious about interdisciplinarity need to invest in support for individuals conducting interdisciplinary scholarship and teaching. Institutions interested in fostering interdisciplinarity should review their administrative processes to determine whether there are impediments to fair review and support of scholars working across disciplines. Administrative structures must be flexible to address the needs of interdisciplinary scholars, as one size does not fit all. Attention to the particulars of the interdisciplinary scholar's position is crucial, starting from the point of position creation to those of a senior faculty member. The life-cycle analysis by the Council of Environmental Deans and Directors (Pfirman et al. 2011) provides guidance for overcoming typical questions and challenges at each stage of career development. Discretionary resources, incentives, and administrative support such as seed funding, incubation grants, co-funding and matching grants, cross-disciplinary workshops and seminars, leaves, travel, and joint or affiliated appointments can go a long way toward helping people overcome personal and professional challenges.

High-level administrative leadership—through a committee or an individual with strong support from the provost level—should oversee the implementation of interdisciplinary activities and fostering of interdisciplinary scholars. Interdisciplinary faculty can thrive when institutions make the investments necessary to create the support structures commensurate with those provided—and taken for granted—by departments and professional societies for those within the established disciplines.

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