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Interdisciplinarity as a Design Problem

Toward Mutual Intelligibility Among Academic Disciplines in the American Research University

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The relationship between institutional design and the advancement of knowledge in the American research university may appear to be a perfunctory administrative matter. Despite broad consensus regarding the imperative for inter- or transdisciplinary approaches to inquiry and scholarship, the traditional correlation between academic disciplines and departments remains the basis for academic organization and administration. As simultaneously epistemological, administrative, and sociocultural categories, disciplines continue to dominate the reflexive relationship between knowledge and its organizational context. This chapter contends that the design of our knowledge enterprises is not merely adventitious to discovery, creativity, and innovation, and that a critique of institutional design is no mere quibbling over the arbitrary disposition of the bureaucratic substratum that supports epistemological superstructures. The prerequisite for successful implementation is mutual intelligibility

between and among academic disciplines and interdisciplinary fields. The concept of institutional design and various "design limitations" in the American research university that impede interdisciplinary collaboration and communication are considered, as well as paradigms for inquiry and organizational and institutional models generally regarded as extraneous in this context. Prototypes for interdisciplinary collaboration examined include "invisible colleges," "communities of practice," "epistemic communities," and knowledge-based theories of the firm. The chapter concludes with a brief case study of the implementation of interdisciplinarity within the broader context of the comprehensive reconceptualization of Arizona State University.

> 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.
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> —A. Hunter Dupree (1957, p. 9)

Introduction

The relationship between institutional design and the advancement of knowledge in the American research university may appear at first glance to be a perfunctory administrative consideration, both self-evident and obvious: "All arts and sciences faculties contain more or less the same list of departments," observes the sociologist Andrew Abbott (2001, p. 126), remarking on the traditional correlation between academic disciplines and departments. While disciplines are now increasingly interrelated or conjoined with rapidly speciating interdisciplinary fields, their identification with academic departments, or, as the case may be, units such as centers, institutes, schools, or colleges, nevertheless often persists. Because of their "extraordinary ability to organize individual careers, faculty hiring, and undergraduate education," Abbott observes, disciplinary departments appear to be the "essential and irreplaceable building blocks" of American academia (p. 128). Similarly, "Americans seem unable to conceive of an undergraduate curriculum without majors. And of course, there are no majors without disciplines" (p. 127). Once consolidated into their present configuration during the final decades of the 19th century, which witnessed the emergence of the American research university, the department-based "American system of disciplines" would remain "uniquely powerful and powerfully unique" (p. 128).

The political scientist Mattei Dogan (1997) offers a corresponding synopsis of the administrative correlate to disciplinary knowledge: "In all universities, teaching, recruitment, promotion, peer review, and administration are organized along disciplinary lines" (p. 429). And from his perspective as

president emeritus of the University of Michigan, James Duderstadt (2000) similarly perceives the "deification of the disciplines," which through departmental structures "continue to dominate the modern university, developing curriculum, marshaling resources, administering programs, and doling out rewards" (pp. 120–121).

The sociologist Immanuel Wallerstein (2003) points out that academic disciplines are "three things simultaneously:

> The so-called disciplines . . . are, of course, intellectual categories—modes of asserting that there exists a defined field of study with some kind of boundaries, however disputed or fuzzy, and some agreed-upon modes of legitimate research. . . . The disciplines are in addition institutional structures that since the late nineteenth century have taken on ever more elaborate forms. . . . Finally, the disciplines are cultures. (p. 453)

While the disciplines and interdisciplinary fields that constitute our academic culture thus first and foremost represent epistemological categories—referring here in the most general sense to the stock of knowledge in any given area—they may be construed secondarily in their administrative contexts, and it is primarily to this organizational substratum of knowledge that in the following we recur. The important sociocultural context of disciplinarity undergirds the epistemological and administrative dimensions, variously construed in terms of the disciplinary cultures—or more equivocally, "social constructs"—that represent the outcome of "disciplinary socialization." Abbott (2001) cautions that assessments of the epistemological "flux" of disciplines must be counterbalanced by an understanding of what he terms the "extraordinary stasis of disciplinary social structure" (pp. 122–125).

Of all that has been said about the reflexive relationship between knowledge and its organizational context, insufficient focus has been devoted to an appreciation of the role of institutional design in the advancement of interdisciplinarity. This reflexive relationship is nowhere more critically instantiated than in the institutionalization of the disciplines and interdisciplinary configurations in the American research university. Any institutional platform constructed to support the growth of knowledge—in other words, any knowledge-producing organization or "knowledge enterprise"—is the product of a sequence of decisions that determine its structure and functions, which may be termed the "design process." While the various strains of interdisciplinarity have been subject to sophisticated explication from any number of perspectives, the concept of "design" in the present context—the advancement of interdisciplinary collaboration in knowledge enterprises, and especially the American research university—is itself often taken for granted or only perfunctorily considered. Whether one focuses on disciplinary genealogies or interdisciplinary confluence, an understanding of the dynamics that determine their institutionalization and dissemination requires

an appreciation of their institutional determination.[1] Inasmuch as the design of our knowledge enterprises is not merely adventitious to the advancement of knowledge, administrators and academicians alike do well to analyze fundamental determinants in the structure and operations of an academic institution that when optimally designed facilitate teaching and research across the disciplines (Crow, 2010).

If by "optimal knowledge production" we assume interdisciplinary teaching and research unfettered by conventional design limitations, the success of the outcome is intrinsically interrelated with an appropriate institutional platform.[2] The prerequisite for the implementation of interdisciplinarity, we argue, is mutual intelligibility between and among academic disciplines and interdisciplinary fields. Within the context of advancing interdisciplinary inquiry, the outcome of optimal institutional design aligned with the various purposes of the university is aptly characterized by Jonathan Cole (2009): "Almost all truly distinguished universities create a seamless web of cognitive influence among the individual disciplines that affects the quality of the whole" (p. 5).

Many academicians, we suspect, would dismiss a critique of conventional academic organization, epitomized by the congruence of disciplines and departments, as mere quibbling over the disposition of the requisite bureaucratic substratum that supports epistemological superstructures. We thus concur with the assessment of John Seely Brown and Paul Duguid (1991): "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" (p. 40). But while abstract knowledge is *prima facie* generally perceived as distinct from organizational structure and attendant social relations, which are deemed nonessential or ancillary, following Anthony Giddens (1984), we contend that to an extent often insufficiently appreciated, knowledge, organizational structure, and social relations are intrinsically interrelated. His theory of "structuration" assesses the "situated activities of human agents" (p. 25). As Scott Cook and John Seeley Brown (1999) explain, structuration treats "praxis as constitutive of social structure, while social structure informs praxis" (p. 399).

It is precisely with the "details of practice" of institutional design that we are here concerned, and in the following we canvass a selection of relevant

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[1]For an extended discussion of the trajectory of the institutionalization of interdisciplinarity in the American research university, see Dabars (2008).

[2]Our usage of "interdisciplinarity" is taken generally to convey the various subtypes that have elsewhere been elucidated specifically, including multidisciplinarity, pluridisciplinarity, transdisciplinarity, and postdisciplinarity. Where distinctions between disciplinarity and interdisciplinarity appear superfluous, we conflate discussion of the categories, consistent with the justification provided by Robert Frodeman and Carl Mitcham (2007): "Both science and society now recognize that disciplinarity and interdisciplinarity are not mutually exclusive but complementary" (pp. 506–507).

theoretical approaches and models applicable to interdisciplinary collaboration in teaching and research. The survey is intended to suggest the range of paradigms for interdisciplinary collaboration and the variety of possible approaches to organizational and institutional structure to provide a foundation for an appreciation of their mutual interrelatedness and relevance to knowledge organizations. As a case study in the large-scale institutional implementation of interdisciplinarity, we conclude with a brief overview of the reconceptualization of Arizona State University during the past decade.

Organizing for Interdisciplinary Collaboration: Transcending the Design Limitations of Our Knowledge Enterprises

The intrinsic impetus to advance new knowledge distinguishes the American research university from other institutional platforms in higher education, but entrenched design limitations restrict their potential to advance discovery, creativity, and innovation. Ubiquitous generalized calls for enhanced interdisciplinary collaboration notwithstanding, we tend to assume that our academic institutions have as a matter of course been optimally structured and moreover inherently calibrated not only to promote effective teaching and research but also to seek knowledge with purpose and link useful knowledge with action for the common good. Leaving aside important considerations of equity and access, the persistence of disciplinary partitioning in our estimation represents one of the most critical design limitations to the further evolution of this set of transformative institutions.

The American research university retains structural characteristics it assumed during its emergence in the late 19th century. During that period, no more than 15 institutions, both public and private, grafted programs of specialized graduate study, modeled on the practices of German scientific research institutes, onto their undergraduate curricula, derived from the British model exemplified by the "ancient universities" of Oxford and Cambridge (Geiger, 1986, pp. 2–3). To this day, the academic organization and practices of the American research university remain to a remarkable extent based on this prototype.

However we conceive the purposes and functions of our colleges and universities, we tend to assume that their organizational structure inherently facilitates the advancement of knowledge. But if the structure of an organization is inimical to its purposes and functions, the design of the institution must be radically reconsidered. Leaving aside academic organization that retains irreducible foundational disciplines such as physics or chemistry, we contend that the entrenchment of universities in conventional discipline-based academic organization often represents the triumph of inertia and bureaucratization. The policy scholar Anthony Downs (1967) specifies that bureaucracies tend toward routine, standardization, and inertia. "Once the

users of the bureau's services have become convinced of their gains from it, and have developed routinized relations with it," Downs explains, "the bureau can rely upon a certain amount of inertia to keep on generating the external support it needs." Moreover, bureaus "tend to develop more formalized rule systems covering more and more of the possible situations they are likely to encounter," which

> divert the attention of officials from achieving the social functions of the bureau to conforming to its rules. . . . They increase the bureau's structural complexity, which in turn strengthens its inertia because of greater sunken costs in current procedures. The resulting resistance to change further reduces the bureau's ability to adjust to new circumstances. (pp. 8, 18–19)

Our academic culture not only perpetuates traditional disciplinary thinking but also assigns inordinate significance to distinctions in an implicit hierarchy. The "gulf of mutual incomprehension" C. P. Snow (1960) observed between what he termed "literary intellectuals" and "natural scientists" more than half a century ago persists. Avowals of parity between the various disciplinary cultures notwithstanding, the prestige and preeminence accorded science in the academy remains undiminished just as disciplines trump other disciplines based on their quantitative capacities. Each disciplinary culture must overcome its ambivalence toward different orientations and approaches to solving problems that may have arisen through more than a millennium of institutional evolution (Crow, 2007).

A corollary to the assumption that the disciplinary configuration of the research university has once and for all been suitably disposed is that research or scholarship is an individual endeavor and that optimal outcomes will inevitably emerge from the amalgamation of the results of individual efforts. Our competitive nature values the individual over the group, and while we valorize the discovery of the unknown by individual scientists, less prestige attaches to collaborative endeavors that target real-world problems and team participation in projects that accomplish assessment, assimilation, synthesis, implementation, and application. Without sufficient coordination and strategic collaboration, however, the ad hoc aggregation of individual endeavors does not necessarily transcend the inevitable limitations of an isolated investigator (Crow, 2007). As Cook and Brown (1999) 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" (p. 399).

Recognizing that such entrenched and arbitrary organizational constructs more likely obstruct rather than facilitate the advancement of useful knowledge, it becomes incumbent on faculties and administrators to remediate the design limitations of their respective knowledge enterprises. We must organize for collaboration across disciplines to establish the preconditions essential to effective teaching and research, as well as constructive social and economic outcomes. Mutual intelligibility between academic

disciplines and robust interdisciplinary collaboration are foundational to all aspects of the academic enterprise. But the persistence of disciplinary entrenchment interrelates with other shortcomings and so must be understood in the broader context of critical societal goals. This, then, is to reiterate the contention that the academy must seek knowledge with purpose and link useful knowledge with action for the common good.

The maintenance of strict disciplinary boundaries undermines the impetus to establish mutual intelligibility with other disciplines. We cannot expect biologists alone to solve the loss of biodiversity, nor chemists in isolation to negotiate the transition to renewable energy. Because each academic discipline has over time developed its own vernacular, the impetus may be lacking to cultivate "interlanguages" intelligible to other disciplines—the "pidgins" or "creoles," which in the metaphor enlisted by Peter Galison (1997) are the mutually comprehensible languages of different subcultures found in "trading zones." The exchanges of knowledge between "theoretical subcultures" thus represent the "movement of ideas, objects, and practices as . . . local coordination through the establishment of pidgins and creoles" (p. 48). But chemists have not sufficiently developed a *lingua franca* to communicate with either philosophers or engineers. The debate must engage a broad community of disciplines and advance not only on the basis of the understanding found within the academy but also the wisdom and expertise developed in commerce, industry, and government (Crow, 2007).

Insufficiently robust interdisciplinary collaboration restricts negotiation of emergent, nonlinear, and unpredictable new complexities and impedes progress in efforts to mount responses to intractable global problems. This lack of adaptive capacity is nowhere more evident than in the institutional posture of our research universities when confronted by the need to address the "grand challenges" of our epoch—one need only think in terms of global climate change, air and water pollution, overpopulation, hunger and poverty, extinction of species, exhaustion of natural resources, and destruction of ecosystems. As the National Academies report on interdisciplinarity considered in the following section explains, such challenges require interdisciplinary collaboration, which facilitates applied research initiatives that often engage large-scale team efforts to address complex and intractable problems (Committee on Facilitating Interdisciplinary Research [CFIR] & Committee on Science, Engineering, and Public Policy [COSEPUP], 2005). Moreover, such collaboration must take place transinstitutionally and transnationally. Only an amalgamation of transdisciplinary, transinstitutional, and transnational frameworks has the potential to advance knowledge and innovation on the requisite scale in real time, as well as desired social and economic outcomes on a global scale.

Applied research initiatives are inherently "use-inspired," which is a concept that informs the critique of the American research university posited in this chapter. The *locus classicus* formulation of use-inspired research comes from the policy scholar Donald Stokes. In an effort to reveal the limitations of the standard binary opposition between basic and applied research,

Stokes constructed a table to represent types of research ("Quadrant Model of Scientific Research"), which may be inspired by the quest for fundamental understanding or considerations of use. In this conceptualization, "Bohr's quadrant" (so called, he explains, for the quest of a model atomic structure by Niels Bohr) represents pure basic research. "Pasteur's quadrant," however, represents "basic research that seeks to extend the frontiers of understanding but is also inspired by considerations of use." The designation memorializes the research of the eminent chemist and microbiologist whose late career was devoted to the development of vaccines that have protected millions from disease: "Pasteur's drive toward understanding and use illustrates this combination of goals" (Stokes, 1997, pp. 72–75).

Consistent with recent discussions of learning or knowledge networks, we contend that conceptualizations of the "flow" of knowledge—as opposed to its accumulation or maintenance within "stocks of knowledge"—represents a fundamental metaphor for enhanced interdisciplinary communication and collaboration facilitated through interpersonal and group dynamics. The inverse correlation between the proverbial "silo mentality" of disciplinary knowledge and the potential for synergies during interdisciplinary exchange is patently evident. Organizational theorists John Hagel, John Seely Brown, and Lang Davison (2010) observe that in the past "we could rely on 'stocks' of knowledge—what we know at any point in time—but these stocks are diminishing in value more rapidly than ever before" (p. 11). Instead, we must "continually refresh our stocks of knowledge by participating in relevant 'flows' of knowledge—interactions that create knowledge or transfer it across individuals" (p. 11). They envisage institutional change thus derived driven not by an administrative elite but rather by "passionate individuals distributed throughout and even outside the institution, supported by institutional leaders who . . . realize that this wave of change cannot be imposed from the top down" (p. 7).

While institutional design is fraught with the potential for unforeseen misalignments between disciplinary factions and may require individuals and groups to transcend entrenched sociocultural barriers, reorganization to enhance interdisciplinary collaboration offers new ways of shaping and examining problems and advancing questions through interaction between heterogeneous groups, programs, and initiatives. Novel interdisciplinary configurations—what are in a sense institutional "experiments"—possess the potential to alter the course of inquiry, discourse, and the application of research, and even to reveal new paradigms for knowledge production, organization, and application. An overarching principle shaping the implementation process could be expressed as follows: If academic units commensurate to the resolution of a given challenge or problem do not already exist, appropriate new units must be configured. In its inception, the new aggregation may simply comprise a best-guess strategic amalgamation of researchers representing different disciplines and interdisciplines or particular specializations. The amalgamation may even begin or remain resolutely multidisciplinary. Such novel organizational configurations may lead to unexpected

discovery through serendipity, the role of which in scientific research has been comprehensively assessed by Robert K. Merton and Elinor Barber (2004). But any such arrangement offers at the very least new potential to address critical challenges or resolve intractable problems—or even evolve into differentiated new interdisciplines. An overarching objective in institutional design is thus to engender an ecosystem of innovation.

New Structural Models for Interdisciplinarity: Practical Advice From the National Academies

Rather than exploring new paradigms for inquiry, academia too often restricts its focus to existing organizational models. The well-known call to action issued by the National Academies regarding the imperative for interdisciplinary collaboration and problem-driven research, *Facilitating Interdisciplinary Research* (CFIR & COSEPUP, 2005), offers an approach that represents a fundamental prototype for institutional efforts to remediate institutional design limitations in this context. The report envisions "scientists, engineers, social scientists, and humanists . . . addressing complex problems that must be attacked simultaneously with deep knowledge from different perspectives," and serves here broadly as proxy for our general recommendations (p. 17). The committee called for new "structural models" 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" and experimentation with "substantial alteration of the traditional academic structures or even replacement with new structures and models to reduce barriers" to interdisciplinary research (pp. ix, xi).

Recommendations for new institutional structures that support the implementation of interdisciplinarity are based on the "matrix model." In contrast to existing configurations of disciplinary-based "silos," the committees recommend structures long evident in industry and government laboratories:

> a matrix, in which people move freely among disciplinary departments that are bridged and linked by interdisciplinary centers, offices, programs, courses, and curricula. There are many possible forms of coupling between departments and centers, including appointments, salary lines, distribution of indirect-cost returns, teaching assignments, . . . curricula, and degree-granting. (CFIR & COSEPUP, 2005, p. 172)

The report similarly stresses the imperative for "institutional policies that govern faculty appointments and salary lines, faculty recruitment, responsibility for tenure and promotion decisions, allocations of indirect-cost returns on grants, development of new course and curricular materials, and so on" (p. 172).

With economic growth increasingly tied to knowledge-intensive innovation, interactions between universities, industry, and government have been critically important during the past half-century. These interrelationships constitute what the economist Henry Etzkowitz (2008, p. 1) terms the "triple helix" of university-industry-government innovation. The National Academies report stresses that interdisciplinary research in industrial and government laboratories should serve as a prototype for academia: "Industrial and national laboratories have long experience in supporting IDR. Unlike universities, industry and national laboratories organize by the problems they wish their research enterprise to address. As problems come and go, so does the design of the organization" (CFIR & COSEPUP, 2005, p. 3). Moreover, "collaborative interdisciplinary research partnerships among universities, industry, and government have increased and diversified rapidly. Although such partnerships still face significant barriers, well-documented studies provide strong evidence of both their research benefits and their effectiveness in bringing together diverse cultures" (p. 3).

New structural models are moreover required 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. (CFIR & COSEPUP, 2005, p. 100)

The implementation of institutional policies conducive to interdisciplinarity is critical for two reasons: (1) Academic careers have historically been forged within strictly demarcated disciplinary delimitations, and (2) disciplinary affiliation defines the social organization of American higher education to such an extent that recipients of interdisciplinary training or practitioners of interdisciplinary scholarship often find recognition among peers and advancement difficult. Such policies must moreover advance recognition of interdisciplinary research by professional associations, business and industry, and, most important, within federal agencies, which in the estimation of this report remain resistant to interdisciplinary categorization (CFIR & COSEPUP, 2005, pp. x, 6).

Communication is intrinsic to the vision for interdisciplinary collaboration of the National Academies committees that produced the report: "At the heart of interdisciplinarity is communication—the conversations, connections, and combinations that bring new insights to virtually every kind of scientist and engineer" (CFIR & COSEPUP, 2005, p. 19). While focused on science and engineering, the report recapitulates the imperative for interdisciplinarity relevant across the spectrum of disciplines. Consistent with its call for new structural models, the report underscores the importance of concordant and supportive institutional policies: "Whatever their structure, interdisciplinary projects flourish in an environment that allows researchers to communicate, share ideas, and collaborate across disciplines" (p. 172).

Institutional Design and the Context for Interdisciplinarity

Institutional design, in our usage, refers broadly to both the process of design and its product, the organizational structure of a knowledge-producing institution and the attendant social formations and networks its disciplinary configuration engenders. The flux that underlies the interrelated and interdependent relationship between organizational form and knowledge is well expressed by Cook and Brown (1999): "It is our contention that there are, in fact, a number of distinct forms of knowledge, and that their differences are relevant, both theoretically and practically, to an effective understanding of organizations" (p. 381). While our approach draws from various perspectives relevant to the design of knowledge enterprises, in this section we consider a number of conceptualizations regarding the role of communication in the enhancement of interdisciplinary collaboration, which we construe as requisite not only for the growth of knowledge but also for the diffusion of innovation.

We begin to conceptualize the basis for an approach to the optimal design of knowledge enterprises using the fundamental distinction between the natural and the artificial explored by the polymath Herbert A. Simon in *The Sciences of the Artificial,* first published in 1969. In his usage of these concepts, "artificial" refers to objects and phenomena—artifacts—that are man-made as opposed to natural. He terms knowledge of such products and processes "artificial science" or the "science of design" and suggests that the most obvious "designers" of artifacts are engineers. But he broadly extends the sphere of the artificial even to 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, as he puts it, while the artificial sciences are concerned with how things ought to be. Artificial science—or design science—determines the form of that which we build—tools, farms, and urban agglomerations alike—but also our institutional and organizational structures. Implicit within Simon's conceptualization is an affirmation of the potential for evolution and differentiation in the structure and organization of knowledge enterprises. There is thus no reason why the redesign of an institution or organization cannot represent a process as focused and deliberate and precise as the work undertaken by scientists and engineers. We may thus begin to assess the design limitations inherent in existing knowledge enterprises and posit new models that better address the complex challenges that confront global society (Simon, 1996, pp. 1–24).

To argue that the advancement of interdisciplinarity may be construed as a "design problem" suggests that the concept of "design" itself in this context may require further assessment. In his collection of essays on the "design process," the computer scientist Frederick P. Brooks (2010) paraphrases the definition of the verb *design* provided by the editors of the *Oxford English*

Dictionary: "To form a plan or scheme of, to arrange or conceive in the mind for subsequent execution" (p. 4). His point is to emphasize the imperative for planning prior to execution, but Brooks overlooks one of the senses of the noun, which in this context seems especially pertinent: "That which is aimed at; an end in view; an ultimate goal or purpose" (*Oxford English Dictionary*, 2012). Inasmuch as the goals or purposes of academic inquiry in a world of emerging complexity might justifiably be characterized as critical to our survival as a species—setting aside for the moment skepticism regarding "weighty metaphysics" and even "truth" claims, as the philosopher Philip Kitcher (2001, p. 11) suggests—we contend that deliberation regarding the design of our knowledge enterprises should become integral to the discourse of our academic culture, if not an aspect of a larger public debate. Further, we maintain that the design of our knowledge enterprises depends on fundamental determinants in the structure and operations of an academic institution that when optimally designed facilitates teaching and research construed across the disciplines.

Brooks (2010) reminds us that the design process both expresses a vision and facilitates its accomplishment. Plato, he informs us, articulated this correlation when in a dialogue he spoke of "corresponding ideas and forms"—for example, the idea of a bed or table facilitating its construction "for our use, in accordance with the idea" (Plato, *The Republic,* Book X, as quoted in Brooks, 2010, p. 6). The execution of the design thus instantiates the idea. While the value of a "design concept" serving to guide the implementation of a plan or execution of an object or construction has been obvious since antiquity—Brooks adduces Vitruvius as an exemplar in the lineage of design—the value for our understanding of interdisciplinary collaboration comes with his point that beyond "conceptual integrity" ("unity, economy, clarity"), a design concept "vastly aids communication within a design team." Adducing as an example the use of storyboards by filmmakers, which facilitate focus on concept rather than details of implementation, Brooks writes: "Unity of concept is the goal; it is achieved only by much conversation." Moreover, "The conversation is much more direct if the design concept per se, rather than derivative representations or partial details, is the focus" (pp. 8–9).[3]

As an epigraph to the first chapter of his book, Brooks (2010) quotes Herbert Simon to underscore the centrality of communication to the design process: "Few engineers and composers . . . can carry on a mutually rewarding conversation about the content of the other's professional work. What I am suggesting is that they can carry on such a conversation about design." Such mutual intelligibility regarding what Simon (1996) terms "common creative activity" is one of the signal characteristics of interdisciplinary collaboration (as quoted in Brooks, 2010, p. 3). With reference to engineering design, Brooks makes the broadly applicable point that because increased

[3]The allusion to Vitruvius is germane to the discussion inasmuch as one may appropriately term the designer of knowledge enterprises a "knowledge architect."

technological sophistication inevitably demands ever more specialization, team design has become the contemporary standard: "The designer of today's state-of-the-art artifact needs help from masters of various crafts" (pp. 66–67).

The exhaustive reconceptualization of an institution undertaken to remediate its design limitations requires "massive change," a concept we adapt from the designer and design theorist Bruce Mau, who together with his colleague Jennifer Leonard conceive of change in terms of "designing systems, designing organizations, designing organisms" to "meet human needs the world over" (Mau & Leonard, 2004). We concur with Mau and Leonard in their assessment that change at this scale requires the exploration of "design economies" wherein the "patterns that emerge reveal complexity, integrated thinking across disciplines, and unprecedented interconnectivity" (pp. 16–17).

Paradigms for Inquiry: A Survey of Theoretical Approaches and Organizational and Institutional Models of Interdisciplinary Collaboration

An appreciation of the implications of the organizational context for knowledge may derive from reference to more than a half-century of empirical study and theoretical analysis, beginning with pioneering work by Thomas S. Kuhn (1970). One account traces the lineage of the "awareness that science is a social formation amenable to sociological investigation" to Kuhn, as well as such figures as Ludwig Wittgenstein, Jean-François Lyotard, and Richard Rorty (Miller & Fox, 2001, pp. 668–669). The foundational work in the sociology of science of Robert K. Merton (1973) similarly provides a conceptualization of "socio-cognitive networks" that underscores the importance of a researcher's milieu in understanding and contextualizing discovery. Derek J. de Solla Price brought historical perspective to assessments of social networks associated with research frontiers as well as quantitative approaches to the proliferation of scientific publications (see Price, 1965b, pp. 510–515; 1986, pp. 103–135).

Approaches including the sociology of science, organizational theory, and social network analysis model interrelationships in scientific and scholarly collaboration and their social institutionalization in a number of organizational types. Analysis of such patterns of collaboration underscores (1) the reflexive relationship between knowledge and its organizational context and social situatedness and (2) the patterns' innate tendency toward interdisciplinary configuration and the imperative role of informal communication in their establishment and maintenance. Economic and organizational theorists have advanced knowledge-based conceptualizations of organizational types and social formations both permanent and transient. Social network analysis and organizational theory continue to evolve in the wake of our increasingly

nuanced conceptions of knowledge. In the following, we briefly canvass a number of models of the organizational or social contexts of interdisciplinary collaboration, beginning with "invisible colleges," "communities of practice," "epistemic communities," and various knowledge-based conceptualizations of the firm. A more expanded analysis of relevant concepts often regarded as extraneous in this context would include "tacit knowledge," elucidated by Michael Polanyi (1983); the "stickiness" of information, as assessed by Eric von Hippel (1994); and the "strength of weak ties," articulated by Mark Granovetter (1973). Following in this tack, the assessment would consider concepts such as clustering, agglomeration, and knowledge spillovers, and would survey the literature on knowledge management, the scientific collaboration networks M. E. J. Newman (2001, p. 404) terms "small worlds," the "interpretive communities" of Stanley Fish, and complexity and patterns of interaction. From a list compiled by Cook and Brown (1999, pp. 381–382), additional themes associated with organizational knowledge and knowledge-based organization would include organizational learning, organizational memory, collective mind, management of intellectual capital, core competencies, patterns of communication, and cognitive systems.

Invisible Colleges: A Prototype for Interdisciplinary Collaboration

An important historical model for interdisciplinary collaboration is found in the knowledge networks known as "invisible colleges," a concept that derives from the early modern period and refers to any informal collaborative engagement of scholars and scientists focused on similar or related problems. Merton attributes the metaphor to the pioneering 17th century chemist and "natural philosopher" Robert Boyle, who coined the term with reference to his peers in the Royal Society of London (Price, 1986, pp. viii–ix). Price explains that these early scientists "communicated by letter to gain an appreciative audience for their work, to secure priority, and to keep informed of work being done elsewhere by others" (p. 119). With reference to the "knowledge revolution" of this period, Joel Mokyr (2002) explains the relevance of the concept thus: "The blossoming of open science and the emergence of invisible colleges—that is, informal scholarly communities spanning different countries, within which seventeenth-century scholars and scientists kept close and detailed correspondences with each other—compounded these advances" (p. 56).

While his objective is to offer perspective on the historical origins of the knowledge economy, Mokyr (2002) offers an assessment of the proliferation of knowledge since the Scientific Revolution that both establishes its grounding within organizations and institutions and traces its circulation through social networks. "The central phenomenon of the modern age is that as an aggregate we know more" (p. 2), he observes, and his analysis underscores that the era was determined not only by the codification of disciplinary

knowledge within universities and scientific institutes but also by its dissemination through social networks and professional societies such as invisible colleges. Only through access to the epistemic base does knowledge become "useful" in the present and for future generations: "Much of the likelihood that knowledge will be transmitted depends on the social organization of knowledge . . . and who controls access to it," Mokyr explains (p. 8).[4]

Much like their historic counterparts, contemporary invisible colleges, which form the "in group" in any given research frontier, serve to advance communication and collaboration (Price, 1986, p. 119). Price (1965a) suggested the scope of a hypothetical invisible college active in contemporary research when he estimated that it would

> correspond with the work of something like the order of one hundred scientists who probably constitute the peer group of a typical new invisible college of all the people who really do the work at that particular segment of the research front. (p. 557)

Such an assemblage represents the vanguard of scientific research in a given arena, for "whenever we see invisible colleges we have research-front science" (p. 567). Price underscored the significance of informal communication in advancing knowledge in such groups: "In fields that are cumulating strongly," he explained, "the news of research flows by personal contact and verbal report through the invisible college and the surrounding peer group" (p. 562) While the process has become "blatantly obvious" only recently, Price deemed it to have been operative since the convention of scientific publication became standard practice in the mid-17th century.[5]

Diana Crane (1969, 1972) characterized the invisible college as a "network of influence and communication" constituted by scientists, sometimes "widely separated geographically," whose "productivity is sufficient to make them visible to most of those who enter the field." Formal collaboration is facilitated through informal communication, which may be "fleeting" or "relatively unstructured." She underscored the extent to which the growth of knowledge and innovation is a "diffusion process" that is at once cognitive and social. Through sociometric data, she demonstrated that social interaction with colleagues despite geographic dispersion—what she termed "relatedness" and "connectivity"—produces cumulative and even "exponential" growth in scientific knowledge through a "contagion process in which early adopters influence later adopters." (See Crane, 1969, p. 349; 1972, pp. 3–5, 22–23, 41–42, 52.) A recent case study of an interdisciplinary research group corroborates her sociometric analysis and finds that in the collaborative

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[4]The invention of the printing press and, more recently, proliferation of ubiquitous information technologies provide unparalleled examples of increased access at reduced costs.

[5]In this context, Price cites the discussion by Hagstrom (1964).

milieu certain individuals inevitably emerge as "interdisciplinary linchpins" (White, Wellman, & Nazer, 2004). Karim Lakhani, Lars Bo Jeppesen, Peter Lohse, and Jill Panetta (2006) present a compelling argument for collaboration in such knowledge networks, drawing the following conclusion: "Lack of openness and transparency means that scientific problem solving is constrained to a few scientists who work in secret and who typically fail to leverage the entire accumulation of scientific knowledge available" (p. 2).

Communities of Practice: Learning as Social Participation

A correlate to institutional design that encourages social interactions conducive to interdisciplinary collaboration is to be found in the concept of "communities of practice" elucidated by Etienne Wenger (1998), which is predicated on the assumption that learning is a process of "social participation." Wenger thus argues that whether one is a mechanic or poet or scientist, knowledge is not only a "matter of competence" but also of active and meaningful engagement. He specifies that whether on the playground or in the office or laboratory, "participation shapes not only what we do, but also who we are and how we interpret what we do" (p. 4). Communication is fundamental to the four interrelated components of his social theory of learning: meaning, practice, community, and identity, each of which he defines as "a way of talking about" the respective aspects of learning. Thus, "community" itself is defined as "a way of talking about the social configurations in which our enterprises are defined" (p. 5).

Wenger (1998) explains that from playground to classroom to workplace to cyberspace, communities of practice are ubiquitous and sometimes "so informal and so pervasive that they rarely come into explicit focus" (p. 7). His examples range from garage bands to the academic research environment: "In laboratories, scientists correspond with colleagues, near and far, in order to advance their inquiries" (p. 6). In this context and relevant to our assessment of the collaborative research environment, Wenger considers the analytical framework of the concept of communities of practice as derivative from theories of both social structure and "situated experience." While theories of social structure underscore the "primacy" of institutions, norms, and rules, theories of situated experience accord primacy to the "dynamics of everyday existence," which include "improvisation, coordination, and interactional choreography" (pp. 12–13).

Paul Duguid (2005) points out the "interdependent tension and dynamism" of such communities, noting that the concept is frequently applied to "transient, cross-functional teams and miscellaneous work groups," which would be typical in academic research. Other social constructs include apprenticeship, which Duguid contends should be construed as "not merely the preferred method of 'manual' trades, but also of the higher reaches of academic disciplines." When dispersed globally, Duguid recommends their conceptualization as "networks of practice" (pp. 112–113, 115).

Participation in communities of practice emphasizes "learning by doing," and Wenger (1998) identifies three conceptual dimensions by which practice becomes a "source of cohesion" for a community: mutual engagement, joint enterprise, and shared repertoire. Through mutual engagement, a community of practitioners negotiates a joint enterprise, which engenders a "communal regime of mutual accountability" that sometimes transcends "reified rules, policies, standards, and goals" (p. 81). Such accountability develops "specialized sensitivities, an aesthetic sense, and refined perceptions" that may become integral to the joint enterprise (p. 81). Wenger identifies the shared repertoire of a community of practice as comprising all facets of the "participative" dimension of the enterprise, including routines, gestures, symbols, narratives, and discourse that in their totality secure the meaning and identity of the enterprise (pp. 72–83).

Of particular relevance to interdisciplinary collaboration, which by some accounts advances on the margins of disciplines,[6] is the conceptualization of marginality and peripherality in learning communities offered by Wenger (1998). On the margins of "regimes of competence" one may find the "wisdom of peripherality," which includes "paths not taken, connections overlooked, choices taken for granted" by core participants (p. 216). Wenger explains that such "legitimate peripheral participation" (p. 100) correlates with the practice of apprenticeship, as disclosed in a number of ethnographic studies (pp. 11, 100–101, 216–217).

"Learning happens, design or no design," Wenger (1998) observes, yet he underscores the imperative for appropriate institutional accommodation because there are "few more urgent tasks than to design social infrastructures that foster learning." According to Wenger, "a learning community must be given opportunities to become involved in the institutional arrangements in the context of which it defines its enterprise." Consistent with the oft-quoted maxim attributed variously to the computer scientist Alan Kay and management consultant Peter Drucker that "the best way to predict the future is to invent it," Wenger writes: "Those who understand the informal yet structured, experiential yet social, character of learning—and can translate their insight into designs in the service of learning—will be the architects of our tomorrow" (pp. 225, 274).

Epistemic Communities: Inquiry as "Cognitive Socialization"

The sociocultural foundation of interdisciplinary collaboration is well represented in the concept of the epistemic community, which has been

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[6]For discussion of a model of interdisciplinary formation that focuses on the fragmentation of disciplines into subfields followed by their strategic recombination or hybridization, see Dogan and Pahre (1990); for contextualization of the model, see Dabars (2008, pp. 45–60).

defined by Hugh Miller and Charles Fox (2001) as a "group of inquirers who have knowledge problems to solve." Any such community shares "norms of inquiry," and while these "vary from community to community," they are determined by tradition, which through "long apprenticeships socialize members of any particular epistemic community" and shape "our institutions and attitudes, our scholarly practices, and our standards of evidence" (pp. 669, 681, 683). While the concept, first introduced by Burkart Holzner in 1968, identifies a type of social formation broadly consistent with communities of practice and other knowledge-based conceptualizations of social organization, it privileges the dynamics of knowledge creation, which Holzner equated with "cognitive socialization" (p. 28).

Epistemic communities are variously conceived, and while the concept is often applied to scientific research, Peter M. Haas (1992) explains, members may come from varied disciplinary backgrounds. He defines an epistemic community as a "network of professionals with recognized expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge within that domain or issue-area." Members of epistemic communities share "set[s] of normative and principled beliefs" that include "notions of validity"—that is, beliefs about what counts as intellectual adequacy within the community. Haas points out that the concept "somewhat resembles Kuhn's broader sociological definition of a paradigm" ("an entire constellation of beliefs, values, techniques, and so on shared by members of a given community"). The community may be interdisciplinary since in this sense the paradigm "governs not a subject matter but a group of practitioners" (p. 3).

Irma Bogenrieder and Bart Nooteboom (2004) contend that epistemic communities tend to be interdisciplinary and problem focused: "Epistemic communities engage in transdisciplinary and/or transfunctional activities, at the interstices between the various disciplines. In contrast with communities of practice, they are not organized around a common discipline but around a common topic or problem" (p. 49). Consistent with knowledge-based theories of the firm, considered in the following section, Lars Håkanson (2010) thus recommends that epistemic communities be "premised on a contextual conceptualization of knowledge" to "denote groups of people mastering the theories, codes, and tools of a common practice regardless of their geographical location" (pp. 1804, 1809).

Knowledge-Based Theories of the Firm: Enterprise as Knowledge Network

American research universities, both public and private, are the primary source of the discovery and innovation that fosters economic and social development at all levels of analysis in the global knowledge economy. Institutional design that engenders interdisciplinary collaboration inevitably advances the basic and applied research that constitutes a critical national

asset. Further critical leverage is attained when we reach out beyond the walls of the academy and engage transinstitutionally. The "triple helix" of university-industry-government innovation described by Etzkowitz (2008, p. 1) represents a series of knowledge networks that inevitably interconnect and leverage respective knowledge bases from diverse and, given the multiplicity of actors, inherently multidisciplinary perspectives. The literature on economic development derived from science-based technological innovation thus offers concepts relevant to our understanding of interdisciplinary collaboration within the research environment (Crow & Dabars, 2012).

In particular, an appreciation of the organizational correlates to interdisciplinary collaboration may be derived from an emerging literature on knowledge-based theories of the firm. David J. Teece (2003) has characterized the firm, referring to a business enterprise either small or large, as a "repository for knowledge," which is "embedded in routines and processes." Competitive advantage derives from the communication of knowledge ("intellectual capital"): "The essence of the firm is its ability to create, transfer, assemble, integrate, and exploit knowledge assets" (p. 149). In a knowledge-based conceptualization of the firm, the enterprise has moreover been construed as a communication network, albeit concerned primarily with variables of specialization and the exploitation of efficiencies: "The internal organization of firms is seen as a communication network that is designed to minimize both the costs of processing new information and the costs of communicating this information among its agents" (Bolton & Dewatripont, 1994, p. 809). Håkanson (2010) even proposes that because "firms offer superior governance structures primarily for knowledge processes, which involve exchanges of tacit, poorly articulated knowledge across epistemic boundaries," they can "meaningfully be seen as epistemic communities in their own right" (p. 1806).

Another analysis proposes that a firm be understood as a "social community specializing in speed and efficiency in the creation and transfer of knowledge" (Kogut & Zander, 1996, p. 503). Bruce Kogut and Udo Zander (1992) invoke Polanyi to underscore the extent to which both explicit and tacit knowledge informs this process: While the "central competitive dimension of what firms know how to do is to create and transfer knowledge efficiently within an organizational context," the capacity to do so derives from the "combinative capability to synthesize and apply current and acquired knowledge" (p. 384). Other scholars, following Pierre Bourdieu, construe "organizational advantage" as derivative of social capital, which is said to engender the creation of intellectual capital. Social capital has been variously interpreted but in general usage refers to the significance of networks of relationships that define individuals or groups, while intellectual capital refers broadly to possession by an individual or collective of various types of knowledge. In one such analysis, social capital produces intellectual capital within a "framework of combination and exchange" (Nahapiet & Ghoshal, 1998, p. 251).

The recognition that firms may be understood as knowledge-centric is confirmed by their correlation with academic, and especially scientific, research groups by Etzkowitz (2003, 2008), whose work both delineates the dynamic interrelationships between academia, industry, and government, and elucidates the broader parallel between academic research and economic development. Indeed, Etzkowitz terms the "entrepreneurial academic model" of the contemporary research university a "teaching, research, and economic development enterprise." He observes that academic research groups have "firm-like qualities, especially under conditions in which research funding is awarded on a competitive basis." Moreover, the "research university shares homologous qualities with a start-up firm even before it directly engages in entrepreneurial activities" (Etzkowitz, 2003, pp. 109–110; 2008). Indeed, along with firms and corporations, universities are key institutional actors in national systems of innovation because of their crucial role in discovery as well as the commercialization of university-based research (Niosi, Saviotti, Bellon, & Crow, 1993, pp. 207–208).

The knowledge-centric social formations considered in this section of the chapter—invisible colleges, communities of practice, epistemic communities, and firms construed as knowledge-centric—represent prototypes for the organization of teaching and research not generally associated with the advancement of interdisciplinarity. Interdisciplinary collaboration may not be strictly required for their operation, but as we have seen in the foregoing assessment, it is generally implicit to their success even if sometimes perceived as merely adventitious. Theoretical discussions of interdisciplinarity tend to overlook such formations, which would probably be deemed extraneous to the repertoire of favoured models. Yet each is relevant to university design because any research enterprise is essentially dependent on its social context and organizational or institutional structure. Recognition of their potential to enhance interdisciplinary collaboration along the epistemological, administrative, and sociocultural dimensions of knowledge described by Wallerstein (2003) may be especially relevant for research universities because these institutions operate on the frontiers of discovery.

The Institutional Implementation of Interdisciplinarity: A Case Study

With simultaneous pressures impelling scholarship toward increasing specialization on the one hand, and greater synthesis, integration, or convergence on the other, the implications of the organizational context of knowledge within the complex matrix of a comprehensive research university are not always readily apparent. Yet the reconfiguration of disciplinary knowledge has the potential to profoundly affect learning outcomes and leverage research transinstitutionally. While chronicles of institutional efforts to implement interdisciplinarity have contributed to a considerable body of analysis, its

conceptualization and implementation at Arizona State University has proceeded largely unencumbered by extraneous rationalization or theoretical justification. In some cases, models of interdisciplinarity—perhaps even including those surveyed in the preceding section—may have served loosely as broad prototypes for new organizational configurations. But in practice, the process—interchangeably referenced as inter- or transdisciplinarity, or even "intellectual fusion"—has been shaped through exhaustive trial and error, a number of course corrections, and the best efforts of administration and faculty at the application of common sense.

During the past decade, the institutional implementation of interdisciplinarity has been one of eight explicit "design aspirations" of Arizona State University (ASU), the nation's youngest major research institution and—with an enrollment surpassing 73,000 undergraduate, graduate, and professional students—the largest university governed by a single administration. ASU seeks to advance knowledge and human well-being through teaching and research conducted within a flexible organizational framework that maximizes collaboration and communication between the core disciplines—some of which remain departmentally based, while others are construed across departments, centers, institutes, schools, and colleges—and new explicitly transdisciplinary configurations. These new academic entities ("new schools") have been established to advance teaching and foster both fundamental and applied research, which possesses the interdisciplinary breadth to address the large-scale "grand challenges."

Because academic organization historically reflected the conventional correlation between discipline and department, the design process from the outset sought to clarify the relationships between core academic disciplines and the new interdisciplinary configurations that emerged (i.e., identity), their disposition within the university (i.e., configuration), and their anticipated evolution (i.e., trajectory). A comprehensive unit-level assessment of the institutional status of disciplines and interdisciplines sought to articulate disciplinary identities and examine their interrelationships, including analysis of each in terms of optimal alignment with fundamental and irreducible disciplines. Assessments of positional embeddedness within institutional coordinates further clarified their interactions and interrelationships. Finally, consideration of trajectory sought to establish the status of an entity within its disciplinary continuum, its role in the emergence of associated interdisciplinary formations, and its relationship to emerging peer entities. These same considerations continue to inform analysis of subsequent proposed organizational reconfigurations.

The implementation of interdisciplinarity at ASU, however, must be understood within the broader and interrelated context of the comprehensive, decade-long institutional reconceptualization launched in 2002, which was conceived with the objective of establishing a foundational model for a "New American University," an institution predicated on the pursuit of academic excellence, inclusiveness to a broad demographic, and maximum societal

impact.[7] While the interplay between the various design aspirations, which include local embeddedness, societal transformation, academic enterprise, and "use-inspired" research, informed the reconceptualization of academic organization and operations, transdisciplinarity is foundational to each and to the entire conception. Rather than extrapolate from existing structure or replicate historical models perceived to represent a putative "gold standard," ASU sought to produce a federation of unique transdisciplinary departments, centers, institutes, schools, and colleges ("schools") and a deliberate and complementary clustering of programs arrayed across four differentiated campuses. In this "school-centric" conception, academic units compete for status not intramurally but with peer entities globally. In the process, ASU has advanced interdisciplinarity through the consolidation of a number of traditional academic departments—including anthropology, geology, sociology, and several areas of biology—which henceforth no longer serve as the sole institutional locus of a given discipline. While more than two dozen new transdisciplinary schools were conceptualized and operationalized, some have been subsequently further reconfigured or merged (Capaldi, 2009).

The differentiation of knowledge enterprises through their interdisciplinary configuration facilitates their integration into coordinated and synergistic networks, thus expanding their potential to offer multiple solutions and exert greater impact across broader swathes of knowledge. Inasmuch as knowledge and innovation flourish when embedded in and interrelated through transinstitutional and transnational networks, the reconceptualized institution has proactively sought to advance connectivity, engaging other academic and research institutions, business and industry, and governments around the world in collaborative teaching and research. Transnational endeavor to lend direction and purpose to the artistic and humanistic insight, social scientific understanding, scientific discoveries, and technological adaptations that are the product of academic culture represents our best hope in surmounting the challenges ahead.

The impetus to rethink discipline-based academic departments began with an ambitious reorganization of the biological faculties to overcome disciplinary entrenchment. In July 2003, the departments of biology, microbiology, plant biology, and the program in molecular and cellular biology merged to form the new School of Life Sciences. While administrative efficiency was cited as an objective, the motivation 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. (ASU School of Life Sciences, 2010, p. 1)

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[7]Michael M. Crow articulated the vision for a New American University when he became the 16th president of ASU in July 2002. See, for example, Crow (2010).

The school was conceived "without internal disciplinary barriers, allowing it to plan strategically at the seams of intersecting disciplines" (p. 2). Faculty groups include biomedicine and biotechnology; cellular and molecular biosciences; genomics, evolution, and bioinformatics; ecology, evolution, and environmental science; and organismal, integrative, and systems biology. Consistent with the prototypes of an invisible college or epistemic community, the arrangement promotes self-organization among life scientists, engineers, philosophers, and social scientists.

Among the new transdisciplinary schools conceptualized and operationalized during the past decade are the School of Earth and Space Exploration; School of Human Evolution and Social Change; School of Politics and Global Studies; School of Social and Family Dynamics; School of Social Transformation; and School of Historical, Philosophical, and Religious Studies. These complement initiatives such as the Global Institute of Sustainability (GIOS), which incorporates the first-of-its-kind School of Sustainability, and the Biodesign Institute, the premier transdisciplinary research center dedicated exclusively to advancing biologically inspired design to address global challenges in health care, sustainability, and national security. The research of this large-scale array of labs and centers working in the broad domains of biological, nanoscale, cognitive, and sustainable systems is aimed at improving human health and the environment through interdisciplinary efforts in such areas as personalized diagnostics and treatment, infectious diseases and pandemics, and renewable sources of energy.

Other transdisciplinary configurations include the Complex Adaptive Systems Initiative, a collaborative effort to address global challenges in health, sustainability, and national security through the creation of new technologies and novel solutions; Security and Defense Systems Initiative, which addresses national and global security and defense challenges through an integrative approach to technology solutions, legal and policy issues, and the root social causes in areas of emerging threats; Flexible Display Center, a cooperative agreement with the U.S. Army to advance the emerging flexible electronics industry; LightWorks, a collaborative effort to advance research in renewable energy fields, including artificial photosynthesis, biofuels, and next-generation photovoltaics; and initiatives in the humanities and social sciences, including the Institute for Social Science Research and Center for the Study of Religion and Conflict.

The School of Earth and Space Exploration (SESE) represents a transdisciplinary conceptualization of the quest to discover the origins of the universe and expand our understanding of space, matter, and time. SESE combines the conventional disciplines of astronomy and astrophysics, cosmology, Earth systems sciences, planetary sciences, and systems engineering. Strategic research initiatives include the emergence of planetary bodies; the origin, evolution, and distribution of life; and the coevolution of Earth's surface environment and human societies. While the conventional disciplines of the Earth and space sciences are predominantly historical, according to planetary

geologist Ronald Greeley and his colleagues (2010), transdisciplinarity offers the potential to "elevate both to predictive sciences" to address such questions as the ultimate fate of the universe (p. 2). Established in July 2006 through 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 boasts a faculty roster that includes theoretical physicists, systems biologists, biogeochemists, and engineers who bring technological expertise that advances the development and deployment of critical scientific instrumentation on Earth and in space.

The School of Human Evolution and Social Change (SHESC) combines the major areas of anthropological enquiry, including archaeology, bioarchaeology, physical anthropology, cultural anthropology, and linguistics, with such areas as mathematics and computer science, geography, political science, museum studies, epidemiology, economics, and sociology. The new school boasts such transdisciplinary research centers as the Archaeological Research Institute, Center for Digital Antiquity, and Institute of Human Origins. The allied Consortium for Biosocial Complex Systems engages the Complex Adaptive Systems Initiative. Transdisciplinary collaboration allows SHESC scientists and scholars to address complex problems from comparative and holistic perspectives, whether the challenge is epidemics of infectious disease, sustainable management of natural resources, or adaptation to climate change. The quest to understand human origins, evolution, and diversity engages research in such areas as societies and their natural environments; biocultural dimensions of global health, culture, heritage, and identity; and global dynamics and cultural interactions. The school thus offers an integrated curriculum in the social, behavioral, and natural sciences focused on the evolution of our species and trajectories of human societies.[8]

The design aspirations are intrinsically interrelated, and the interplay between interdisciplinarity and efforts to advance sustainability as a core value is representative of their dynamic. With the establishment of the GIOS in 2004 and School of Sustainability 3 years later, ASU has positioned itself in the vanguard of interdisciplinary research on environmental, economic, and social sustainability. In a social network reminiscent of an invisible college or epistemic community, the institute brings together scientists and engineers with government policymakers and industry leaders to conduct research in areas as diverse as agriculture, air quality, marine ecology, materials design, nanotechnology, policy and governance, renewable energy, risk assessment, transportation, and urban infrastructure. Sustainability is thus representative of the interdisciplinary theme-based approaches that epitomize the reconceptualization of the university.

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[8]See ASU School of Human Evolution and Social Change, *Seven-Year Program Review (2005–2011)*, http://shesc.asu.edu/, and http://casi.asu.edu/.

Each institution must advance a differentiated profile, determined by its mission and setting; the character of its academic community; the scope of its constituent colleges, schools, and departments; and the extent of its commitment to public service and community engagement. Any comprehensive reconceptualization of an organization or institution must thus proceed according to its own intrinsic logic, especially in the case of an institution as complex as a major research university. The purposes of this chapter, therefore, do not include the articulation of a set of design prescriptions applicable in all contexts. Rather, our intent has been to call attention to the focus and deliberation that must be expended on institutional design in general, including the problem of how to structure institutions to foster more meaningful interdisciplinarity.

Toward Interdisciplinary Knowledge Enterprises

Even before the advent of organized science and the formation of the modern research university, our intellectual progenitors 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 standpoints commensurate to the challenges that confront us. During this same time frame, through our increasingly sophisticated manipulation of limited knowledge coupled with brute force and an astonishing measure of hubris, we have shaped a world that in all likelihood cannot sustain our collective standard of living. Although disciplinary specialization has been key to scientific success, such specialization can diminish holistic understanding. It has also diminished our ability to construe teaching and research between and among the disciplines. Our academic culture, 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.[9]

Concern with institutional design and optimal organization for research may well be subsumed in more epistemologically grounded discussion; indeed, the question, "How should inquiry be organized so as to fulfill its proper function?" has been crucial to modern science, as we are reminded by the philosopher Philip Kitcher (2001), beginning with the quest of Bacon and Descartes for suitable methods of discovery and justification. The quest for a "community well-designed for the attainment of epistemic goals" elucidated by Kitcher—balancing consideration of social institutions with abstract knowledge—requires no further justification (pp. 109, 113).

[9]An analysis of human limitation in this context is to be found in Crow (2007). See also Frodeman, Chapter 6, this volume.

The well-known observation by University of California president emeritus Clark Kerr (1982) that universities dominate the list of institutions established before 1500 that still exist "in recognizable forms, with similar functions, and with unbroken histories" expresses the intergenerational sweep of great teaching and research. Against the present backdrop of encroaching complexity, it is obvious that we need new ways to conceive the pursuit of discovery, creativity, and innovation, to understand and build our knowledge enterprises, and to endow academic culture with meaning for people other than academicians. Our collective survival as a species may depend on our capacity to adapt and innovate, which assumes mutual intelligibility between and among academic disciplines and interdisciplinary fields, and knowledge enterprises designed to engender interdisciplinary collaboration.

Take-Home Messages

- The relationship between institutional design and the advancement of knowledge in the American research university is no mere perfunctory administrative matter.
- Despite broad consensus regarding the imperative for inter- or transdisciplinary scholarship, academic disciplines continue to dominate academic structures and practices at both the institutional level and transinstitutionally, in their relationships with other institutions, industry, and government.
- Institutional design has the potential to remediate design limitations inherent within the American research university, including those that impede interdisciplinary inquiry and collaboration.
- An appreciation for the reflexive relationship between knowledge and its organizational context may be derived from theoretical approaches and organizational models generally regarded as extraneous to interdisciplinary analysis.
- Inasmuch as the design of our knowledge enterprises is not merely adventitious to the advancement of knowledge, administrators and academicians alike do well to advance their understanding of and appreciation for institutional design.

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