1

A Vision of Interdisciplinary Research

Interdisciplinary research[1] (IDR) can be one of the most productive and inspiring of human pursuits—one that provides a format for conversations and connections that lead to new knowledge. As a mode of discovery and education, it has delivered much already and promises more—a sustainable environment, healthier and more prosperous lives, new discoveries and technologies to inspire young minds, and a deeper understanding of our place in space and time.

> We are not students of some subject matter, but students of problems. And problems may cut right across the borders of any subject matter or discipline.
>
> Karl Popper[2]

Interdisciplinary research and education are inspired by the drive to solve complex questions and problems, whether generated by scientific curiosity or by society, and lead researchers in different disciplines to meet at the interfaces and frontiers of those disciplines and even to cross frontiers to form new disciplines.

[1]The definition of IDR is provided and discussed in Chapter 2.

[2]Popper, K. R. Conjectures and Refutations: The Growth of Scientific Knowledge. New York: Routledge and Kegan Paul, 1963, p. 88.

The history of science from the time of the earliest scholarship abounds with examples of the integration of knowledge from many research fields. The pre-Socratic philosopher Anaximander brought together his knowledge of geology, paleontology, and biology to discern that living beings develop from simpler to more complex forms. In the age of the great scientific revolutions of 17th-century Europe, its towering geniuses—Isaac Newton, Robert Hooke, Edmond Halley, Robert Boyle, and others—brought their curiosity to bear not only on subjects that would lead to basic discoveries that bear their names but also on every kind of interdisciplinary challenge, including military and mining questions.[3] In the 19th century, Louis Pasteur became a model interdisciplinarian, responding to practical questions about diseases and wine spoilage with surprising answers that laid the foundations of microbiology and immunology. Today, the proliferation of new understanding about the molecular and genetic underpinnings of life demonstrates the power of combining disciplinary knowledge in interdisciplinary ways.

In recent decades, the growth of scientific and technical knowledge has prompted scientists, engineers, social scientists, and humanists to join in addressing complex problems that must be attacked simultaneously with deep knowledge from different perspectives. Students show increasing enthusiasm about problems of global importance that have practical consequences, such as disease prevention, economic development, social inequality, and global climate change—all of which can best be addressed through IDR. A glance across the research landscape reveals how many of today's "hot topics" are interdisciplinary: nanotechnology, genomics and proteomics,[4] bioinformatics, neuroscience, conflict, and terrorism. All those invite and even demand interdisciplinary participation. Similarly, many of the great research triumphs are products of interdisciplinary inquiry and collaboration: discovery of the structure of DNA, magnetic resonance imaging, the Manhattan Project, laser eye surgery, radar, human genome sequencing, the "green revolution," and manned space flight. There can be no question about the productivity and effectiveness of research teams formed of partners with diverse expertise.[5]

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[3]Robert K. Merton's classic *Science, Technology and Society in Seventeenth Century England* describes the work of the remarkable "natural philosophers" whose reach spanned many of today's disciplines.

[4]Study of all the proteins encoded by an organism's DNA.

[5]A recent editorial in *Science* notes, "The time is upon us to recognize that the new frontier is the interface, wherever it remains unexplored. . . . In the years to come, innovators will need to jettison the security of familiar tools, ideas, and specialties as they forge new partnerships." Kafatos, F.C. and Eisner, T., "Unification in the Century of Biology." *Science*, 303 (February 27):1257, 2004.

On an individual basis, studies[6] show that situational factors, such as exposure to ideas outside one's own discipline, may have a positive impact on researchers in their own discipline. Prolific and influential researchers are more likely to keep up with developments outside their own domains, and this interdisciplinary curiosity can lead to major breakthroughs on their own projects. For example, it was Charles Darwin's reading of Malthus's "An Essay on the Principle of Population" that led to his theory of natural selection.

Convocation Quote

One of the things that I have observed is how increasingly the fields of sociology, bioethics, and economics are necessary to execute our missions in the apparently harder sciences as we move ahead.

Jeffrey Wadsworth, director, Oak Ridge National Laboratory

Academe has responded to the burgeoning specialization of knowledge and increased cross-fertilization by creating new hybrid research fields—such as bioengineering, biogeochemistry, and paleoseismology—and innumerable courses of study that explore the interstices between traditional disciplines (see Box 6-9 and Appendix D).

The administrations of many campuses have begun to respond vigorously with renewed energy and innovative organizational structures. After several decades of experimentation, interdisciplinary centers, institutes, programs, and other structural mechanisms have proliferated on and adjacent to university campuses; indeed, these research units often outnumber traditional departments (see Figure 1-1 and Box 1-1). Despite frequent tensions over budgets, space, and intellectual turf, many of these centers and institutes are vibrant research and training environments. They do not supersede the departments but complement them, often generating new kinds of excitement.

[6]Feist, G. J. and Gorman, M. E. 1998. The Psychology of Science: Review and Integration of a Nascent Discipline. *Review of General Psychology* 2, no. 1:3-47; Simonton, D. K. 2004. *Creativity in Science: Chance, Logic, Genius, and Zeitgeist*. New York: Cambridge University Press; Simonton, D. K. 2003. Scientific Creativity as Constrained Stochastic Behavior: The Integration of Product, Person, and Process Perspectives. *Psychological Bulletin* 129, no. 4:475-94.

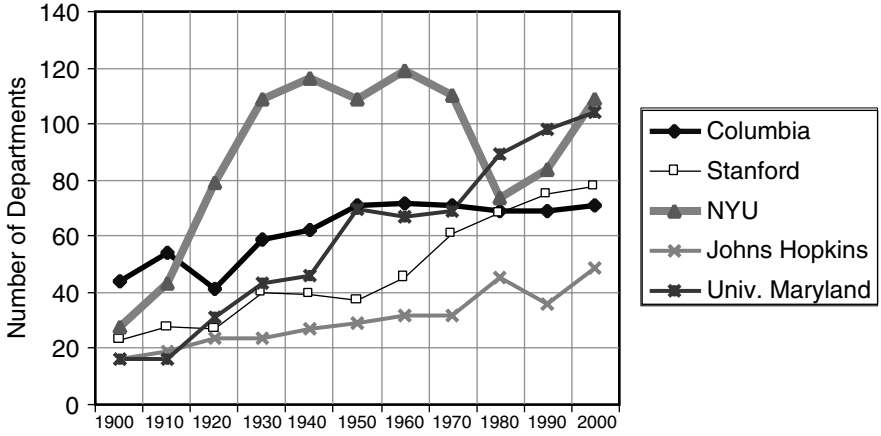

FIGURE 1-1 Number of departments at selected universities, 1900-2000.
NOTES: The number of departments has increased steadily over the last century, from about 20 in 1900 to between 50 and 110 in 2000. National professional societies have also increased in number from 82 in 1900 to 367 in 1985 (see Figure 7-1). Although those changes may appear to indicate increasing specialization, the increases in new departments, such as biophysics and biochemistry, and societies, such as neuroscience and photonics, reflect a blending of previously distinct fields.
SOURCE: The Committee was able to obtain department lists from small and large public and private institutions across the United States. NYU decreased after 1970 because the departments on their two campuses (University Heights and Washington Square) merged around that time.

KEY CONDITIONS FOR INTERDISCIPLINARY WORK

During the preparation of this report, practitioners of IDR and other contributors described some of the key conditions for effective IDR. They include sustained and intense communication, talented leadership, appropriate reward and incentive mechanisms (including career and financial rewards), adequate time, seed funding for initial exploration, and willingness to support risky research (see Table 1-1).

CONVERSATIONS, CONNECTIONS, COMBINATIONS

At the heart of interdisciplinarity is communication—the conversations, connections, and combinations that bring new insights to virtually every kind of scientist and engineer. Just as a biologist (Watson) and a

STRUCTURE/POLICIES

BOX 1-1 University Departments and Centers. Case Study: Columbia University

Columbia has been extremely supportive of interdisciplinary education and research, but it, like many other universities, has almost no publicly accessible records of the administrative structures used to facilitate such work.

Departments of instruction at Columbia are established by the trustees and written into the university statutes. Therefore, there are accurate records of their number. A list of current departments is published in the *Faculty Handbook*.[a] For historical information, prior handbooks are available in the archives.[b] Since 1950, department numbers have fluctuated (see Figure 1-1). Numbers alone, however, are not very enlightening. In each of the decades since 1950, some departments have been eliminated and replaced by others as the university shifted its academic priorities and some departments have been allowed to linger in the university statutes long after they cease to be functioning entities. A statutory count does not reveal how widely the university has dispersed its energies.

Unlike departments, centers, institutes, and other interdisciplinary units are not written into the university statutes. Institutes are supposed to require the approval of the university senate and the president. In contrast, centers and other interdisciplinary units can be created by the individual schools and in practice have often been established without even the approval of the dean. There is no central approval or recordkeeping. Lists of the interdisciplinary units were compiled for the university's last two accreditation reviews, in 1996 (105) and 2001 (241). In 2004, there were 277 such units. There are no counts for years prior to 1996.[c] Even more than academic departments, institutes and centers can vary substantially in size, resources, and contributions to the university. Some are bigger and intellectually more influential than some academic departments. Others are highly specialized and narrow. Some have existed for decades, others disappear after only a few years, and still others merge to create new units or emerge when one interdisciplinary unit is split. Some have retained their original purpose throughout their lifetimes; others have substantially shifted their academic focus. Aggregate numbers cannot reflect this diversity.

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[a]The Columbia University Faculty Handbook is available on line at *http://www.columbia.edu/cu/vpaa/fhb/*.

[b]Columbiana Library Web Page *http://www.columbia.edu/cu/columbiana/collection.html*

[c]"We were not as systematic in our counting in 1995 as we were in later years and we, therefore, may have understated the number that actually existed in that year." Steven Rittenberg, Vice Provost, Columbia University, email communication, March 19, 2004.

TABLE 1-1 Key Conditions for Successful IDR at Academic Institutions Based on Committee Interviews with IDR Leaders and Scholars

Aspect	Key Conditions
Initial Stages: Building Bridges	• Common problem(s) to solve • Leadership • Environment that encourages faculty/researcher collaboration • Establishing a team philosophy • Seed/glue money • Seminars to foster bridges between students, postdoctoral scholars, and PIs at the same institution • Workshops to foster bridges between investigators at different institutions • Frequent meetings among team members • Think of the end at the beginning
Supporting the Project	• Science and engineering PhDs trained in research administration • Support project initiation and team building • Seamless and flexible funding • Willingness to take risks • Recognize potential for high impact • Involvement of funding organization
Facilities	• Physical co-location of researchers • Shared instrumentation • Enhance chance meetings between researchers, such as on-site cafeterias
Organization/ Administration	• Matrix organization • Rewards for academic leaders who foster IDR • Tenure/promotion policies for interdisciplinary work • Utilize experts with breadth and IDR experience for assessment • Professional recognition of successful practitioners of IDR

physicist (Crick) a half-century ago enriched their insights with evidence from x-ray crystallography to imagine the structure of DNA, scientists in every research area are alert to flashes of understanding from other fields that may illuminate their own specialties. Without sustained and intense discussion of such possibilities and without special effort by researchers to learn the languages and cultures of participants in different traditions, the potential interdisciplinary research might not be realized and might have no lasting effect. Learning a new field is always hard work, and it must be catalyzed by both formal efforts, such as institutional policies that support

new programs, and informal efforts, such as cafeterias, collaborative spaces, and common rooms that encourage mingling and conversation.[7]

The task of this report is to update and illuminate the intrinsic power of IDR and to build on models and recommendations that can identify and remove barriers to its full expression. A similar task has been assigned to research councils in Europe (see Boxes 1-2 and 1-3).

The purpose and current research agenda of IDR must be examined more closely than they have been by scholars. Should we be moving from a gradual trend toward interdisciplinarity to one that is even stronger? What is the proper response to the many knowledgeable observers who continue to advise "staying in one's long-cultivated disciplinary garden" as "the best way to produce the fruits of scientific discovery"?[8] In seeking the best ways to support research, policy makers must address difficult institutional, fiscal, and behavioral issues; they must also find better ways to assess the effectiveness of different research and teaching settings.

A QUESTION OF URGENCY

Much depends on the nation's response to the challenges described in this report. Strengthening IDR is not merely a concept that is philosophically attractive or that serves the special interests of a few neglected fields. It has been vital since the creation of our great research universities—and critical during times of national emergency. It has led to major new industries and opened up the world to the creation of wealth, to international collaboration, and to enhanced technology and scientific exchange.

Convocation Quote

There is this long-standing call for this type of research. The question we have to ask ourselves is, what is the problem? Why isn't this proceeding at a more rapid rate?

Cliff Gabriel, deputy associate director,
White House Office of Science and Technology

[7]Participants in the committee's Convocation on Facilitating Interdisciplinary Research (see Appendix C) emphasized the importance of a conscious strategy to promote informal communication.

[8]Feller, I., Whither Interdisciplinarity (In an Era of Strategic Planning)? Presented at AAAS Annual Meeting, Seattle, WA, February 15, 2004.

STRUCTURE/POLICIES

BOX 1-2 (1+1) > 2: Promoting Multidisciplinary Research[a] in the Netherlands

In 2002, the Dutch ministers of education, culture, and science (OC&W) and the minister of economic affairs (EZ) jointly asked the Dutch Advisory Council for Science and Technology Policy (AWT) for advice on how to foster multidisciplinary research.

The council's recommendations, published in 2003, are based on the central observation that multidisciplinary research is growing in importance. Scientific discoveries occur increasingly on the borders between disciplines. In addition, economic and social innovations call for input from a variety of disciplines.

In its recommendations, the council focuses on universities. It found that the obstacles to multidisciplinary research manifest themselves most emphatically in such institutions, which, paradoxically, are best positioned to gain from IDR. Universities play a key role in the knowledge infrastructure. After all, many of the students and research assistants trained at universities are the future "producers" and "consumers" of the results of research.

The recommendations are practical and grouped along three issues that, according to the AWT, are indispensable for the effective promotion of multidisciplinary research:

- Ensure that there are enough motivated researchers. Incentives are required to encourage scientists to engage in multidisciplinary research. In this connection, the council makes statements about a variety of subjects, including the desired broader definition of scientific quality, the broadening of university career policy, and the need to improve the image of multidisciplinary research.
- Promote interaction and meetings. Tangible measures are required to put this into practice. The council calls for the creation of more horizontal ties at universities and for the establishment of institutions to lead research in societal issues.
- Set challenging goals. Multidisciplinary research can be successful only if the goal, question, or ambition is attractive and shared. In this context, the council believes that it is essential to ensure that all the relevant disciplines are involved from the beginning. The council also presents concrete tools for achieving that.

In addition to the universities, the recommendations address the Ministries of OC&W and EZ, the Netherlands Organization for Scientific Research, and the Royal Netherlands Academy of Arts and Sciences.

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[a]Report 54. (1+1) > 2. Promoting Multidisciplinary Research. September 2003. Advisory Committee for Science and Technology Policy (AWT). Available on the AWT home page *http://www.awt.nl/en/index.html*. Although the term multidisciplinary is used in the Netherlands, its definition fits the committee's definition of interdisciplinary (see Chapter 2).

STRUCTURE/POLICIES

BOX 1-3 Interdisciplinary Research in Europe: The EURAB Report[a]

The European Union's research advisory board (EURAB)[b] released a report in April 2004 detailing the barriers to carrying out IDR in Europe and making recommendations as to how such barriers can be overcome.

EURAB found that barriers to IDR are highest where the traditional one-department, one-discipline structure of most universities is reflected in the structures of research funding bodies. Specific challenges include the difficulty of creating new interdisciplinary programs by using established one-discipline funding systems, the weakness of multidisciplinary career structures, the lack of established interdisciplinary scientific journals, and education systems that are not geared toward producing multidisciplinary graduates and postgraduates.

EURAB recommendations focused on a reassessment of disciplinary demarcations, a removal of structural and administrative barriers in and between institutions, and a rethinking of associated research training.

The report suggests that a reduction of the number of de facto definitions by which research funding is allocated would be helpful in creating greater opportunities for interdisciplinarity. EURAB cautioned against the unwitting creation of barriers to IDR when EU expert groups or advisory boards are being created.

With regard to the education and training of researchers, the report notes a need to provide bridges between disciplines at the undergraduate level and warns that overspecialization at the doctoral level creates barriers to industrial employment. EURAB recommended establishing a high-level EU interdisciplinary doctoral program and encouraged universities to provide opportunities for undergraduates to take credit modules outside their own specialties.

With regard to creating new IDR centers, EURAB recommended examining the advantages of virtual centers. When a new structure is proposed, the cost and benefits should be evaluated against the reform or extension of existing traditional disciplinary structures. EURAB recommended that any new center integrate teaching and research activities of traditional disciplinary departments.

Finally, with regard to research funding agencies, EURAB recommended transparent mechanisms to review interdisciplinary proposals, which may include flexible allocation to discipline-based review panels with cross-referencing and joint evaluation. In addition, EURAB requested a review of mechanisms that are used by EU and national funding agencies to design, evaluate, and manage IDR.

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[a] Interdisciplinarity in Research, EURAB, April 2004. Available on line at *http://europa.eu.int/comm/research/eurab/pdf/eurab_04_009_interdisciplinarity_research_final.pdf.*

[b] European Research Advisory Board (EURAB) home page *http://europa.eu.int/comm/research/eurab/index_en.html.*

To hinder this activity is to diminish our ability to address the great questions of science and to hesitate before the scientific and societal challenges of our time. If a disjunction exists between how science naturally moves and how various structures hold it back, the task is to mend it.

The literature that this committee has reviewed suggests an evolution in modern research toward greater complexity. If that is valid, researchers need organizational and career structures that are suitably flexible and carefully designed to support the trend.