THE ROLE OF AMERICAN COLLEGE AND UNIVERSITY FACULTY IN THE INDUSTRIAL INNOVATION PROCESS

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I. THE DEVELOPMENT OF COLLEGES AND UNIVERSITIES IN THE UNITED STATES

To understand the role of American college and university faculty in the Industrial Innovation Process, it may be useful to trace some of the forces that have shaped the development of America's institutions of higher learning. An appreciation of these forces should provide insights into the changing relationships of America's colleges and universities to the nation's business enterprise and government. In particular, the reasons for the

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preference of university researchers for more academic topics should become clearer.

The American college, from its beginnings, was an expression of public purpose. Support for American colleges during the colonial period came from a few wealthy businessmen, the state, and modest public subscriptions, sometimes of labor. Labor subscriptions erected Nassau Hall at Princeton and the Bullfinch Building at Andover Theological Seminary (1). Only with the industrial revolution did sizable college endowments begin to materialize.

Churches also started colleges and supported many promising ministerial candidates. The inability of domestic philanthropy, however, to meet the growing needs of higher education, increasingly brought state funding. It may be of interest to note here Rudolph's quote from a speech given by Harvard's President Eliot in 1873. In that speech, Eliot argued against a tax-supported national university saying, "Our ancestors well understood the principle that to make a people free and self-reliant, it is necessary to let them take care of themselves, even if they do not take quite as good care of themselves as some superior power might" (1).

As Rudolph congently points out, had this principle actually been well understood by Mr. Eliot's ancestors, there would have been no Harvard and no presidential office there for him to use against the principle of government-financed higher education. On over one hundred occasions, before 1789, the general court of Massachusetts appropriated funds for Harvard College, which clearly was not capable of taking care of itself. Indeed, Harvard, Yale, and Columbia could not have survived the colonial period without support of the state (1).

It was not until after the Civil War that truly private colleges began to emerge. Their many instances of prior state support were forgotten or overlooked by the advocates of private colleges. Moreover, they commonly came to regard government support as insidious and potentially dangerous.

A major event for American education occurred with the passage of the Morrill Act in 1862. This act established state land-grant colleges. These land-grant colleges met the demands for practical vocationalism, yet honored the spirit of scholarship defining the new university movement. With the land-grant college also came the highly successful research and extension services which transformed American agriculture.

A new model for the American University appeared in 1874. The Johns Hopkins University was structured on the German model and created the respected profession of university teachers. It emphasized scholarly inquiry and recruited studnets that would provide this faculty-centered institution with challenge and stimulation. The Johns Hopkins University also established the practice of subsidizing promising graduate students from everywhere. The first fellows at Hopkins included Herbert Baxter Adams, Henry C. Adams, Walter Hines Page, and Josiah Royce.

An important development in American Higher Education after the Civil War was the flowering of the state university movement. During this time, state legislatures increasingly came to see the university as potentially useful in providing for broad social benefits. The pattern for the state-university movement was exemplified by the universities at Michigan, Minnesota, and Wisconsin. Their underlying concept was the establishment of a unified system of free education on the European pattern. As Rudolph states, however,

> *The rise of the state universities to eminence was a perilous process. They survived the suspicions of the people themselves, and in time, as they would clearly demonstrate toward the end of the century and at the beginning of the next, they would combine in a typically American institution that Jeffersonian emphasis on excellence and learning which had become the special com-*

mitment of Johns Hopkins and the Jacksonian emphasis on numbers and on the practical which had become the special commitment of the land-grant colleges (1).

The colleges in their university phase now became broadly centered in American society. An expanding and growing economy generated a university response that some formal body of knowledge existed, largely supplanting the apprenticeship system of the old professions and bringing a whole range of vocations toward professional status. Despite these changes, which made higher education more relevant to the needs of business and commerce, scholarly research goals received growing emphasis.

In 1866, Cornell's President stated, "In an institution of learning, facility and power in imparting truth are even more necessary than discovering it." Yet before the turn of the century, the President of the University of Chicago said, "...the network of investigation (is) primary, the work of giving instruction secondary" (1). Promotion at Chicago became dependent upon scholarly publications and, in the ensuing years, an increasing number of America's universities adopted this dictum, if not in statement then in fact. Scholarly publications and research honors of university faculty also became the pre-eminent measure for determining the relative academic status of universities. Thus, the emergence of scholarly research as a principal goal of the American university, whether it be private, public, or public land-grant in origin, gives it a distinguishing characteristic. Moreover, the nature of this research emphasis is closely linked, in theory, to the teaching function. The theoretical linkage between teaching and research also provides a straightforward rationale for the prsent administrative structure of the university research function.

II. TEACHING, RESEARCH, AND THE "UNITY" PRINCIPLE*

Until World War II research criteria were built into the departmental system and course structure and had come to dominate faculty selection (at least in theory if not always in practice). The main operating resources of the colleges and universities came from, and were justified in terms of, undergraduate teaching functions. Therefore, in the organizational resource allocation process, research criteria remained largely implicit, or even covert. The administration of teaching activities underwent much extensive elaboration over time—in an accounting system and, more recently, as a crude measurement of efficiency and performance tied to the resource allocation process.

The Ad Hoc, scattered and individual character of direct research support, thus did not lend itself to such administrative rationalization, with the important exception of agricultural research supported by government. The activity of greatest interest and concern to the faculty, paradoxically, remained administratively invisible. This pattern of invisibility and informality of massive government research funds greatly expanded research employment in the university. The question then became, on what basis could those people and activities be integrated into the university?

Looking at the catalogues of contemporary American universities, one is struck by the pervasiveness and apparent fixity of the departmental geography. Despite this impression of permanency, "The curriculum is in constant flux; the experiments of one decade become the institutions of the next."

There are several factors which contribute to the apparent

**This section is taken from Chapter II of the unpublished doctoral dissertation of Carlos E. Kruytbosch which he provided the authors (2). Dr. Kruytbosch is presently executive secretary of the National Science Board.*

stability of the departmental structure. One of these is the national organization of the academic profession into scholarly and scientific associations which correspond closely to the departmental geography. Formally and informally, the professional associations set the standards for admission to the profession, as well as criteria for professional prestige and honor. The associations also operate to maintain the boundary lines demarcating the various disciplines from one another. This becomes particularly important in the organizational framework of the university, where institutional resources—budgets, space, facilities, students—are allocated by disciplinary groups (departments). It also poses some difficulties for academic researchers pursuing interdisciplinary topics.

Academic departments, then, represent assemblages of men certified as meeting the standards of more or less well-defined scholarly or scientific disciplines. The twin manifest functions of departments are: 1) to "profess" the established configurations of the discipline to students and to provide appropriate witness to the degree of proficiency attained by the student, and 2) to examine critically these configurations or subsets of them, to devise appropriate tests of, and commentaries upon them, and to propose and explore alternatives.

The student credit hours (weighted and modified by a standard teaching load factor) is currently the standard basis for budgetary allocations at most large universities—especially public institutions. A department's budget depends, at least formally, upon the number of credit hours it offers. And, of course, it is the large undergraduate introductory courses that provide the bulk of these units—even when unfavorably weighted. Hence, there is incentive at the departmental level to continue this type of offering.

Finally, the departmental structure represents an accommodation of the academic man—one who is qualified to instruct by virtue of his demonstrated research performance—symbolized by the Ph.D. The department came to form the basic organizational unit of the American university, and the evolving conceptions of the academic role have been posited upon an assumption of departmental controls. The administrative objective of the expenditure of resources in the educational enterprise has become the "production" of student credit hours, ultimately applied toward degrees.

There is no such convenient measure of research productivity. Two widely used yardsticks are proximate "spectacular" applied results, or agreement among the researcher's peers that his work is sufficient. Both of these criteria figure in the assessment of faculty members for appointment and promotion. It is widely held in general, but admitted by none in particular, that as the mere fact of publication can be taken as evidence of the acceptance of a piece of work as significant, the number of publications is a good index of research productivity.

Although a faculty member can get a fairly clear idea of how much teaching will be expected of him, it is unclear as to the amount of significant research he must produce. Not only are the ends of research vaguely specified, but the means are not obviously available in the institutional structure.

The point is that while the teaching function has become administratively routinized, with a stable and visible measure of resources and well worn administrative and legislative channels for coordinating the activities, faculty (and student) research is considerably less institutionalized. When "research" primarily connoted individual scholarly activity, the main resource necessary was time.

Before the Second World War, while academic interest and concern was focused on research, professors' time was taken up predominantly with classroom teaching. At least such evidence as is available suggests that teaching loads at major universities declined after the war. For example, a comparison of teaching loads in 1938-1939 and 1963-1964 in two departments at Berkeley showed unmistakable reductions in listed classroom hours.

The post World War I increases in support for research took place in the context of a heightened level of research and development activity: private business made little contribution to university research, certainly less than the philanthropic foundations and other noncommerical agencies.

By the mid-1930s, it was estimated that $56 million annually was being spent on university research—with 14 institutions accounting for half the total.

The gains in resources for university research, more obvious in retrospect than at the time, did not alter the feeling that research was playing second fiddle.

The research "institute" had been incorporated into the university and reconceptualized the whole enterprise of higher education in the process, but by itself it had little legitimacy outside the academic profession. Apart from a few experiments (such as Johns Hopkins), graduate education and research as the major defining values of institutions of higher education were not viable concepts. The public image of the new university continued to be based on the collegiate life. In light of this image, university research enterprises were seen as a prestige-giving, sometimes useful, but clearly a secondary, activity. Research-oriented academics, then as today, saw undergraduate teaching as a price to pay for the security and the freedom to engage in their chosen research activities.

In sum, then, during the late 19th and early 20th centuries, systematic scientific research was institutionalized in American society within the framework of institutions of higher education which had as their major functions undergraduate teaching. The fact remained, despite the insistence upon a faculty who would publish, that research was only one among a number of concerns which commanded the attention of academic administrators.

A central element of the conception of the academic role in the multifunctional United States university that evolved during the past three-quarters of a century, is "the unity of teaching and research." Ashby (3) has observed that this idea—"Einheit Von Forschung and Lehre"—was taken over from the German prescription and, "received in the graduate schools an almost ritualistic devotion..." In the American university, however, the idea came to be a major justification for requiring both graduate and undergraduate teaching responsibilities of faculty members. It stressed the complementarity of intellectual innovation and the diffusion of ideas, and the consequent desirability of including both activities as requirements of the academic role. It posited that all academics were expected to engage in both activities. Whatever the intrinsic merits of the argument, it is clear that in the early period of the emergence of the American university, this ethic served the function of permitting the weak and "precarious" social value of research to be hitched onto the strong social value of instructions and hence to partake of the resources supplied for instruction.

The idea of the unity of teaching and research is formally expressed in university regulations and guidelines and criteria for appointment and promotion. Such written and unwritten policies invariably stress a high level of performance in both areas, as well as "service" in other areas.

On the other hand, studies of faculty attitudes and beliefs about their systems of appointment and promotion show, almost invariably, that professors believe there is a preponderant emphasis upon evidence of scholarly research performance in the implementation of promotion criteria.

The "unity" concept more or less precluded the emergence of the "research professor," although, of course, constant pressures and considerable semi-legitimate use of time and resources in this direction can be identified. It is a matter of record that the "research professorship" was never adopted as a pattern role in American universities. ("Research professorship" in this context is defined as a faculty member, having full tenure rights, collegial voting privileges in the department and the institution, but whose duties do not include an expectation of classroom teaching.

III. UNIVERSITY-INDUSTRY INTERACTIONS

There is a long history of university-industry interactions, much of it mediated by the federal government. The previously mentioned Morrill Act of 1862, which established land-grant colleges, provided the first major mechanism to directly relate educational developments (in agriculture) to private sector performance. This marked the birth of the vast agricultural extension system, with its well-articulated technology transfer aspects, county agents, and the like. In the 1930s, engineering experiment stations were established at land-grant colleges to duplicate the agricultural model. They were supported primarily through university and state funds (4). Significant federal support for public science began prior to World War II, when the Department of Agriculture established the largest scientific research program in the federal government. This program supported research at state colleges and experimental stations.

World War II brought an unprecedented coupling of business and academic talents in support of national defense. The most obvious example of this collaboration was the Manhattan project. Some have argued that this period marked the watershed of university-industry relations and Shapero (5), for one, believes that the only convincing evidence that university research *can* stimulate industrial economic activity comes from university-industry cooperation on national defense projects during the two world wars. At any rate, the post World War II experience was a turning point, apparently inspired by the success of war-time efforts. Federal administration policy sought to strengthen the nation's basic research capability during peace time. Particular initiatives at the end of World War II included the creation of the National Science Foundation (NSF) in 1950. This marked the beginning of large-scale federal funding to universities for basic research.

This change in the amount of federal funding was the beginning of university dependence on federal support and the isolation of academic institutions and faculty from societal needs and industry R & D research priorities. In turn, industry efforts moved from basic to applied research and development activites.

> *During the years after the war the ability of America to convert science into industrial application was considered the outstanding strength of both American science and industry.* (6)

Whether this was, in fact, a result of on-going university-industry relations, or whether industry was "living-off" the war-time collaborative activities, is unclear. Drucker (7) has argued that the increase in federal funding for university research following World War II changed the direction of university training and employment, as well as university research priorities.

The launching of Sputnik in 1957 triggered another shift in emphasis and another decade of expansion in federal research support. Once again, paralleling World War II, much of this was earmarked for a "national priority." In response to what was perceived as a scientific challenge by Russia, the federal government increased R & D expenditures, particularly in the space industry. Universities received a large share of these funds.

To recapitulate, three major trends substantially altered the interaction between universities and industries during the twenty years following World War II. First, there was the estrangement of academic and industry researchers. Second, university graduates became less-oriented toward industrial careers because of expanding employment opportunities in academia. Finally, there was a lessening of industry involvement in basic research (8).

Interaction between universities and industry continued through the 1960s, although on a relatively reduced level. Traditional linkage mechanisms included consultancies, unrestricted research funding by industry for universities, employment of graduates by industry, and interaction via technical meetings, visiting professorships, advisory committee memberships, etc. (6).

The emergence of major social problems substantially changed the direction, in terms of mission area, of federally-supported R & D in the mid-1960s. An increasing amount of funding was redirected from defense, aerospace, and atomic energy to the civilian sector, i.e., environment, health, transportation, energy, and urban issues (6). In the 1970s, there was a resurgence of R & D growth based on the energy crisis, the recognized need to make up for lags in the defense effort, the continuing emphasis on health research, and the development of the space shuttle. Despite the shifts and course corrections in the disciplinary focus or content of R & D, one factor has remaind constant: the decisions by successive administrations to build support for research as an essential national resource and as a continued heavy concentration on basic research in the university setting.

In spite of the important federal support for basic research, a number of factors are currently forcing government, industry, and academia to focus on more collaborative efforts. The general concern about technological change has already been noted, but other factors are also present. For universities these factors include: diminishing general financial support; increased competition for federal research funds; decreases in enrollment; fewer career opportunities in universities; outdated university research facilities; and the increasing federal emphasis on accountability for support (6). Inflation, taxes, and the increase in government regulations has led industry to look for ways to increase their science base without increasing in-house R & D expenditures on equipment or personnel.

IV. UNIVERSITY FACULTY CONSULTING—ITS ROLE AND LIMITATIONS IN THE INNOVATION PROCESS

One of the oldest and most widely practiced mechanisms for knowledge transfer between university and industry is the consulting relationship. Typically, a company contracts with a university faculty member to provide information or training in a specific area for a short period of time. The extent of corporate funding of such activities varies considerably within and across industries, as does the extent of faculty involvement across disciplines and universities. University administrators and faculty committees typically view consulting activities as falling within the "unity" concept. The rationale for consulting then becomes the enhancement of teaching effectiveness. In some disciplines consulting is important to academic advancement. For example, faculty members in a college or school of architecture are commonly encouraged to do consulting in order to gain pedagogically useful information on current industry practices and procedures.

Faculty consulting is a formally recognized activity and is generally governed by specific regulations. These regulations, however, may be honored more in the breach than in practice. Variations in these regulations between universities may be rather wide, but the terms of these regulations tend to reflect the "unity" principle. In the establishment of a policy on faculty consulting relationships many factors are considered. Features found common to all universities are:

1. consulting without compensation as public service; and
2. consulting with compensation as professional development.

Universities seek to appoint and to retain faculty and other professional staff members of exceptional competence in their respective fields of professional endeavor. Recognizing that these institutions are a public body of unique expertise, a certain amount of consulting is encouraged in the form of information, discussion, and counsel as a part of the faculty members responsibilities. Such assistance to individuals, professional organizations, or firms can generally be rendered informally and usually requries only a small effort or investment. Other recognized activities include those undertaken as members of professional associations, membership on review or advisory panels, review or editing of scholarly publications, etc.

Universities encourage consulting and other professional services for pay. By engaging in these activities for pay, individuals have an opportunity, through the practical application of their own capabilities in teaching, research, and other university service. There is, however, a limitation and a needed approval of such activities. Also, university policies usually limit consulting work to that which is reasonable and worthwhile. (It is also interesting to note that most regulations concerning consulting limit the time that may be devoted to it by a faculty member—usually not more than one day per week—presumably to assure a proper balance between internal and external activities.) Worthwhile consulting excludes routine activities which do not contribute directly to a staff member's development. Other often stated limitations include a prohibition on: 1) the inappropriate use of university facilities, equipment, or personnel; 2) the use of the university name for any purpose other than professional identification; and 3) any claim of university responsibility for the outcome of consulting activities. Universities normally require an annual report from each staff member on consulting activities.

Consulting still remains, however, an avenue for faculty participation in the innovation process, despite imposed university limitations.

V. THE ROLE OF UNIVERSITY FACULTY IN INDUSTRIAL INNOVATION—THE PROGRAMS OF THE INDUSTRIAL SCIENCE AND TECHNOLOGIES INNOVATION PROGRAM WITHIN THE SCIENCE, TECHNOLOGICAL, AND INTERNATIONAL AFFAIRS DIRECTORATE OF THE NATIONAL SCIENCE FOUNDATION

Since the early 1970s, the NSF has acted to spur industrial innovation through a series of programs. In a recently completed reorganization at the NSF, the Division of Industrial Science and Technologies Innovations (ISTI) was created to bring together, for the first time, the various specific programs designed to further industrial innovation. It is expected that this administrative change will strengthen the managerial attention and the focus provided for such programs. In turn, this should enable us to better assess what we are accomplishing.

Our goal of contributing to the improvement of United States technological innovation concentrates on removing market imperfections. This increases the products and services available to the public. Our approach is supporting reasearch in four closely-coordinated programs. These programs are:

1. The Industry-University Cooperative Research (IUCR) project which stimulates the development of linkages between university and industry research by supporting joint industry-university research.

2. The Small Business Innovation Research (SBIR) program which supports high-risk research by small businesses oriented toward science and high-technology to stimulate technological innovation.

3. The Industry-University Cooperative Research Centers program which helps to establish university centers, supported

jointly with industry, which can conduct research in technological areas that are closely related to industrial needs. The university-based innovation centers are primarily concerned with researching the innovation process, developing curricula treating entreprenuership and innovation, invention evaluation, product development and a clinical research approach to new business initiation. (The innovation center funding will be terminated in fiscal year 1981, but NSF responsibility for monitoring the centers will continue at least through fiscal year 1982.

4. The Innovation Processes Research program supports and conducts studies and analyses on innovation processes, practices, and mechanisms, in order to improve the information base for action by NSF and others.

The Industry-University Cooperative Research program supports collaborative research projects in engineering and projects in materials research, chemistry, physics, computer science, and biology. In every case, NSF funding is provided partly by the IUCR and partly be the relevant NSF disciplinary research program. Each project also receives a significant contribution from industry. However, public funds are not used to purchase equipment for use in private industry.

The program supports high-quality research that involves strong collaboration between university and industry scientists and engineers in performing research that explores the scientific basis for new technological possibilities, or that addresses important problems in current technologies.

One IUCR project, jointly supported with the NSF Chemistry Division, has advanced basic chemical knowledge about the dynamics of electron transfer in oxygen reduction, and has provided a new direction for seeking efficient catalysts to make the hydrogen-oxygen full cell a practical and economic possibility. The research was proposed and conducted by scientists at Hercules, Inc., Standford University, and the California Institute of Technology. This oxygen-electrode project can be traced back to a long-term consulting relationship between Dr. Howard Tennant at Hercules and Dr. Henry Taube at Stanford, particularly to a Hercules research project performed by Tennant and consulted upon by Taube.

Similarly, another project started under the NSF program, Research Applied to National Needs (RANN), in 1973, was designed to conduct research on electrodes and electrolyte for a sodium-sulfur battery. It became clear that although patents had been issued, fundamental information concerning fabrication of the ceramic electrolyte, corrosion problems, and sulfur electrode processes was required. The research was proposed by the Ford Motor Company, the University of Utah, and Rensselaer Polytechnic Institute, and led to an energy conversion and storage device in which both Beta-Alumina and Rutile Ceramics could be used in the sodium sulfur battery. As a result of the research, the University of Utah investigator, Professor Ronald Gordon, established a small high-technology ceramics firm (of which he is now presidnet). The firm, Ceramatec, Inc., in Salt Lake City, Utah, currently employs 23 persons.

The review of these projects suggests that several conditions must be met for successful collaboration on a project of basic research exploring for a technological breakthrough. These include:

1. Organization of sufficient specialties to cover the project while maintaining the correspondence of long-term specialist interests with the separable aspects of projects;

2. University-industry participation in the project;

3. Formal means of sponsorship of the project and communication between groups in the project; and

4. A strategy for exploring basic science mechanisms within

the context of technological and commercial criteria.

The NSF Small Business Innovation Rsearch (SBIR) program encourgaes small business firms to submit research proposals which have a high potential for leading to significant industrial innovations.

The program operates on a three-phase concept for each project. In phase I, competitive awards of approximately $30,000 are made to determine the technical feasibility of proposed research projects.

Those projects which appear most promising are selected for Phase II awards, which average about $200,000 and can run as long as 24 months. Phase II is designed to allow in-depth research leading, if successful, to a technology which is ready for commercial development. Completion of phase II marks the end of NSF support.

Phase III is conducted with private funds and leads, if successful, to a commercially marketable product. Typically, support is provided by a venture capital firm or a larger manufacturer, who is willing to participate because the work in phases I and II has reduced the risk of technological failure. Although not a requirement, preference for phase II awards is given to projects which have a commitment of private funds to pursue phase III development, contingent on success in phase II.

The program supports projects that, because of the high risk involved, could not attract private investment during the early research phases.

All proposals receive peer review as part of the evaluation process. Also, the past practice of conducting regional conferences to acquaint small business entrepreneurs with the SBIR program, as well as possible opportunities for funding by other federal agencies is continuing.

The success of the program has been substantial, both in terms of the response of the small business community and in terms of the availability of private support for phase III. Since the inception of the SBIP program in 1977, participating firms have more than doubled their employment since submitting their phase I proposals. Private investment in the firms receiving phase II awards is now about $20 million. NSF funding for these firms was about $5 million. The following are two examples of their success.

1. *OMEX Corporation* received $182,000 from NSF for research on a large capacity computer information storage. Their work was successful and attracted follow-on private venture capital from the Heizer Corporation, a large Chicago venture capital firm. This supported work resulted in a $4 million contract to produce equipment for the nation's largest title insurance company. This is an important new approach to large scale computer filing of documents; the outlook for further growth is extremely favorable. The OMEX Corporation employed consulting services from faculties at three different universities.

2. *Collaborative Research, Inc.* received $264,000 from NSF over three years for genetic research. The company received $8-to-$9 million of additional private investment from one of the nation's largest chemical companies, and it expects to receive another $20 million to further expand its genetic work in the near future. The firm had 33 employees at the time of the first award, and today has approximately 90. Collaborative Research, Inc. had close involvement on its research program by faculty from Harvard University and the Massachusetts Institute of Technology, one of whom was a Nobel Laureate.

Overall, of the first 21 phase II awards, 19 had university faculty research involvement.

The Industry-University Cooperative Research Centers are jointly supported by NSF and industry and are responsive to industry's research needs as well as university research interests.

They deal with research on techniques and processes with broad applicability within an industry rather than specific products. The objectives of each center are: 1) to perform research that is compatible with university objectives and meets industry needs; and 2) to become self-sufficient through support by industry in 3-to-5 years. Research programs of centers capitalize on the university's scientific and engineering expertise and support the interdisciplinary activities necessary to meet the industry's research needs. Joint support of centers by NSF and industry encourages the university to develop a broad-based research program responsive to the scientific needs of industry. As the research programs mature, industry support increases and NSF support decreases.

Centers are initiated only when there is significant industrial interest and potential for cost-sharing by companies leading to center self-sufficiency. An example of one of these centers is the Center for Research on Polymers at the University of Massachusetts, Amherst Campus. The center organizers received a one-year grant to plan a research program. Based on the results of the planning grant, the center was initiated in 1980 to conduct research on preparation and solid properties of polymers. Initial industrial sponsors, which provide more than half of the center's support are: Allied Chemical, Aloca, ARCO, Celanese, Dow Chemical, DuPont, EXXON, General Electric, Kendall Co., Colgate-Palmolive, Eastman Kodak, Monsanto, Union Carbide, and Westinghouse.

An earlier center, now fully self-supporting by industry sponsors, is the MIT Polymer Processing Center. The operating mode of this Center, which was started in 1973, is focused around the Director. The three major functions in the operation of the Center are administration, research, and interaction with participating industries. The first of these is accomplished by the Director with advice and consultation of the Industrial Advisory Council and with institutional support from MIT. The Council consists of senior representatives of the industrial participants, the MIT Vice President for Research, the Director, and a senior representative of the MIT Center for Policy Alternatives. The research function is performed primarily be graduate students (supervised by the Director), with participation and supervision by other faculty and staff. Industry interactions are focused on quarterly technical review meetings attended by 30-to-40 people, about equally divided between MIT program staff personnel and representatives of the industrial participants.

At these meetings, the research program is reviewed by the Director and the graduate students; participating faculty members give reports on their active research projects. Considerable interaction ensues between the program staff and industrial representatives—vice presidents and managers of research and operational entities. This operational structure has been highly successful, but demands an exceptional director to bear the heavy burden of the required responsibility.

NSF provided some $450,000 over a five-year period, with the support declining in the last two years of the experiment. During this period, the center built up industrial support; it now receives over $500,000 annually from twelve companies. The NSF financial support ceased in July 1978.

Another form of center experiments are the Innovation Centers. The objectives of these centers include: increasing the number of technological entrepreneurs emerging from the university; establishing an atmospher in which innovation occurs; increasing the use and commercial exploitation of new technology developed at the university and in the community; encouraging the development of technology-based companies; and increasing the success rate of small technologically-oriented businesses.

The centers activities include: curricula and educational program development; product and process development and assistance; researching the innovation process; and the creation, for the first time, of lines of communication among innovators, entrepreneurs, venture capital organizations, new product-oriented companies, and interested educators and organizations.

A major function of the centers is to provide straightforward, low-cost evaluations of ideas by university students, faculty, and staff, and community inventors. If an evaluation is sufficiently favorable, the inventor may be asked to submit a brief application containing a summary of goals, plans for development, and a description of the assistance sought. At this point, the inventor would be introduced to the formal requirements of the center and encouraged to enroll in an individualized study program at the unviersity to pursue the idea in more detail.

The center may, for especially promising concepts, negotiate arrangements to provide specialized services such as laboratory studies, machine shop services, computer time, and hiring of consultants needed to enhance the development of the product toward eventual commercialization. In many instances, the best business strategy for the technological innovator is licensing the new product to existing industry. The Innovation Center, through its wide-ranging contacts with individual firms, can assist the innovator in locating specific firms that are likely to be interested in the product. Executives in such firms (when dealing with a project recommended by the center), can be assured that the idea is sound and that thorough business planning has been undertaken. Finally, the center would continue to be available to provide research and consulting help to new businesses to insure positive growth.

The last program in this area is the Innovation Processes Research program, which supports research and analyses to improve understanding of the processes by which technological innovation occurs and how those processes are affected by federal actions. One example is a study gathering data from several venture capitalists to identify how they make decisions concerning support of small high-technology firms. The intent is to determine obstacles to the acquisition of venture capital by small firms, and the implications of these obstacles relative to federal programs.

VI. A NATIONAL SCIENCE FOUNDATION PERSPECTIVE ON THE ROLE OF UNIVERSITY FACULTY IN THE INNOVATION PROCESS

From the foregoing description of the ISTI Division of program experiments, it should be clear that these efforts hasten the application of scientific breakthroughs occuring in university laboratories to industrial use, provide considerable experience in university-industry research linkages.

These experiments have tended to confirm the difficulty of achieving congruence between university and industry research interests.

The application of the "unity" principal to university faculty research produces, essentially, basic research, by simply asking the question, *why?* For example, Professor Watson at Harvard University discovered the double Helix by asking, "*Why* are creatures different?" The result of that discovery, of course, led to the current boom in biogentics and bioengineering—but these later results did not motivate the original research. Similarly, Einstein's early theoretical work led to the feasibility of the Manhattan project, whose longer term consequences continue to unfold.

Thus, research at leading universities is in the nature of questioning: *why?* Its accomplishment is rewarded by academic advancement and scholarly status.

Applied research, by contrast, asks, "How can some required result be achieved?" Business management asks, "What can we do with such results to make a profit?"

These latter two questions provide the appropriate focus for industrial R & D, although in larger, very profitable firms, some limited amount of basic research is pursued.

The fundamental problem then, in achieving industry-university research linkages, is meeting industry needs while preserving the spirit of free inquiry by university faculty. Research into the nature of our universe is primarily performed by the university within the context of its purpose. The university provides rewards for basic research by its faculties, since its immediate value to industry is likely to be very small.

University faculty who shift their research interests more toward the "how?" question, in response to industrial needs, do so at the risk of some cost in academic standing. This, then, is a primary barrier to closer United States industry-university research linkages. The ISTI program serves to address this barrier, by experimenting with alternative institutional arrangements through which the results of basic research are more quickly seized upon by industry.

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UNIVERSITY-INDUSTRY COOPERATIVE PROJECTS

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I. INTRODUCTION

Technological and industrial innovations are central to the economic well-being of the United States (1-4). Innovation provides a basis for economic growth and is related to productivity, inflation, unemployment, and competitiveness of United States products. Efforts to enhance innovative activity, therefore, may lead to a generally improved economy in the United States (2).

Universities are major performers of the research that is transformed by industry into technological advances. The flow

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of information between campus and industry is an important element in both scientific and technological advance (3).

As shown in Fig. 1, the separation of industry and university as presently exists—and has always existed—needs to be removed and industry and university move toward positive areas of cooperation. Although university research often provides the underpinning for industrial innovation, we are now beginning to believe that often the reverse is true. Industrial innovation often influences university research. The process is iterative as shown in Fig. 1.

In the past, industries and universities were separated, as shown in Fig. 1(a). Some university-industry programs are now appearing, as shown in Fig. 1(b). However, for real industry-university programs to work, there must exist areas of clear overlap, as shown in Fig. 1(c).

Technological innovation usually takes place in industry and quite often is based on university findings. The effective use of research results may be increased by a coupling of academic and industrial research. Insights available to industrial researchers are different from those available to faculty researchers. If industry and university insights could be more intimately communicated we might find more positive research directions.

A variety of experiments have begun during the past several years in the United States to strengthen industry and university relations. These experiments will test the effects of cooperation between universities and industry to stimulate industry R & D activities that show promise of long-term social, educational, and private economic benefits (4).

One program funded by the National Science Foundation (NSF) is the University-Industry Cooperative Research Experiment. The objective is to determine if federal cost-sharing, during a five-year period, would enable the creation of industry-funded, permanent, cooperative, research centers. Since 1973 through 1981,

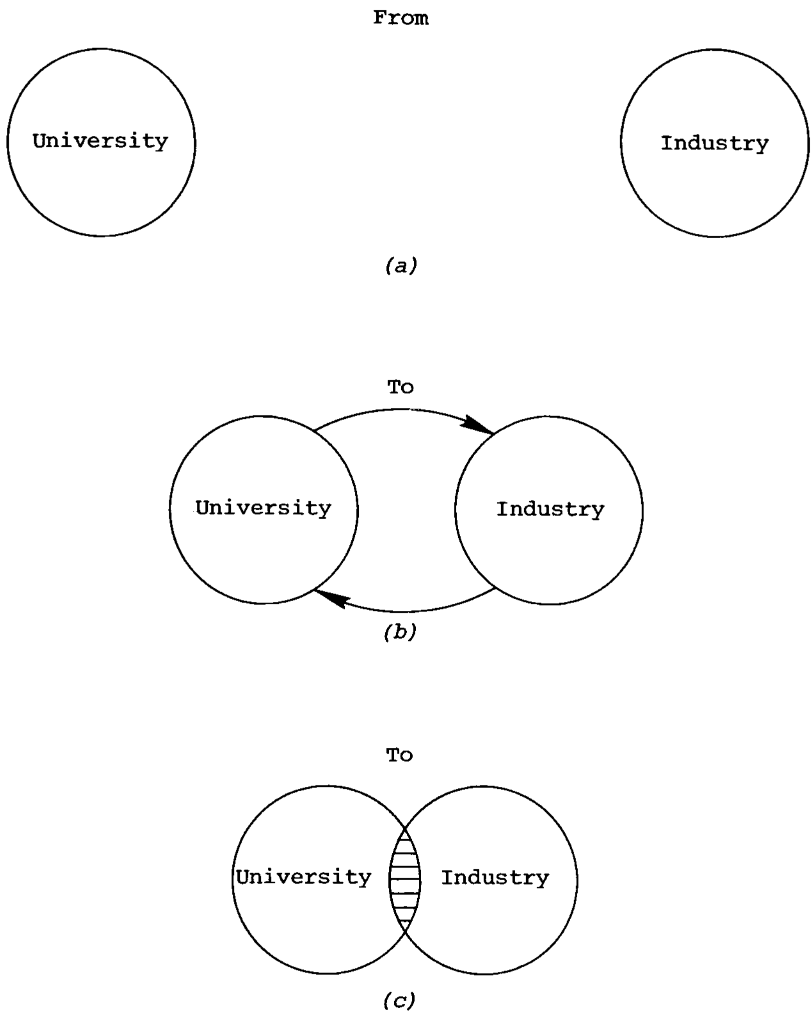

FIGURE I. University-Industry Connection

NSF will have established eighteen centers for cooperative research and innovation at an annual cost of about $3,000,000. The first three centers that opened were operated at North Carolina State University, Massachusetts Institute of Technology (MIT), and the Mitre Corporation. They addressed, respectively, the R & D needs of the furniture industry, the polymer processing industry, and the energy-related industries. Operational approaches of each of the Centers differed, but the objectives, schedule, and incentive structure were common. Firms obtained special benefits from participation. They were allowed to protect proprietary interests and share in patent rights ensuing from the research (5,6).

The NSF findings indicate that the major characteristics for establishing successful university-industry cooperative programs focus on three areas: 1) leadership role; 2) university resources and support commitment; and 3) industrial participation.

The MIT Center, which emphasized polymer processing, originated in 1973 with seed funding from the NSF-Experimental R & D Initiatives Program. It is now supported by twelve industrial firms, which pay membership fees ranging between $20,000 and $80,000. Results from the program's R & D are provided first to the industrial participants, giving them early opportunity to exploit the ideas generated. Representatives of member companies meet quarterly with the MIT faculty, staff, and student researchers to discuss research results and plans. An Industrial Advisory Council, comprised of executives from participating companies and individuals from MIT, advise on fees, patents, and other policies. The Program Director, in consultation with member firms, suggests future research projects and, with Council agreement, decides which projects will be undertaken.

At present, an all-out effort is underway by United States universities to attract corporate investment in university research. Some companies report that grant requests by universities have increased by as much as 100 percent.

The Wydler Stevenson Technology Innovation Act of 1980 is designed to promote innovation through cooperative research between universities and a consortium of industrial firms. The act is a culmination of several years of effort by those who have supported the idea that the private sector in the United States needs to be strengthened through more effective utilization of existing institutional resources. It is intended to provide a mechanism for industrial innovation while still maintaining a competitive element between firms (7).

II. EXAMPLES

Some of the more prominent examples of industry-university cooperative research are as follows:

1. Exxon's Agreement with MIT to Fund Research on Combustion

Exxon's agreement with MIT for combustion research, announced in April of 1981, meets the criteria that many observers say are necessary for successful industry-university collaboration: direct people-to-people relations and extended support. Exxon will provide MIT a total of $7 million to $8 million over a period of ten years to study such problems as the burning of coal and coal liquids, and heavy crude oil. The objective is to develop more efficient fuels. Exxon selects specific projects from a list of proposals generated at the university. The professors involved in these projects will devote at least half their time to this research. However, MIT can, at its discretion, use twenty percent of the funds available for other combustion studies.

MIT will be able to patent results from the work and Exxon will receive a royalty-free license to use the patents. Exxon and MIT will share any license fees from other users. All patents, generated from the research, must be licensed without delay at reasonable rates to interested third parties.

The MIT-Exxon agreement provides that each Principal Investigator devote up to fifty percent of his research time to the research agreement. The program is guided by a Project Committee composed of four persons: two reprsentatives from MIT and two representatives from Exxon. The Committee initiates changes in project direction, budgets, and filing for patents. Exxon has the right to review proposed reports before publication and the right to delay publication up to 90 days.

2. Monsanto Co.-Harvard University Program on Biochemisty

Monsanto Co. supplies both money ($20 million) and technology to support Harvard's fundamental research on the biology and biochemistry of organ development. For example, Monsanto provides services and large-scale quantities of experimental materials from its research analytical, and pilot plant programs that Harvard would be unable to produce or buy on its own. Monsanto researchers work in parallel in their own laboratories in St. Louis with the Harvard scientists; therefore, ideas and information are exchanged freely and easily. Thus, Monsanto has a window on the current world of biological and medical research, as well as help in building its own research capabilities in areas where it had not been active earlier.

Harvard researchers, in turn, can carry out their work as they see fit and are free to publish their findings. So far, about 100 publications have come out of the program.

They also can patent results of the work they do, with Monsanto having an exclusive right, for a limited period, to commercialize useful products developed through the research. One unusual aspect of the agreement is an Advisory Board (whose members have no formal connection with either Harvard or Monsanto), set up to ensure that public interests are served. A reserach project can be terminated by either partner, but only with long-term notice. Both parties can publish their own work with advance notice to the other.

3. Westinghouse-Carnegie-Mellon Program on Industrial Robotics Robotics

In the Westinghouse-Carnegie-Mellon arrangement, both the Westinghouse R & D laboratory and the Carnegie-Mellon research facilities are located near each other in Pittsburgh. The research is carried out at Carnegie-Mellon by university professors with close input from Westinghouse engineers. Basic research on forces and vibrations between tools and workpieces during machining operations relate to Westinghouse turbine blade manufacturing. The university research on industrial robot systems using vision, relates to a Westinghouse need for automated assembly of transistors to printed circuit boards. In each case the basic research was influenced by the application need.

4. WPI-Emhart and WPI-NSF Industry

The Worcester Polytechnic Institute (WPI)-Emhart Corporation agreement calls for Emhart to allocate approximately $700,000 in the first year for improving productivity through the use of industrial robots and microprocessors. Emhart is a large multi-product manufacturer ($1 billion sales) involved in the manufacture of fasteners (rivets, etc.), glass products, shoe machinery, injection molding equipment, and glass processes. The objectives of this university-industry relationship are somewhat different for each of the two partners. A major objective for Emhart is to experiment with advanced automation to improve productivity. One objective for WPI is to have Management students and Management, Mechanical Engineering, Electrical Engineering, and Computer Sciences faculty become skilled in applications leading to problem solutions. WPI faculty and students work in close cooperation with engineers from Emhart. Of particular uniqueness is the fact that Emhart engineers are physically located on the WPI campus. When they do return to the plant the projects are then supervised by knowledgable engineers. Projects are nominated by Emhart and approved by the WPI faculty. However, difficulties exist regarding the long-term commitment of Emhart and the heavy drain on faculty resources.

The other WPI-industry program is one that is partially funded by the National Science Foundation (NSF) and partially funded by a group of firms. The plan is to have the government (NSF) provide funding to start the program (approximately $100,000 per year for the first few years) and have several companies also contribute. As the industry component increases, the government component decreases so that by year five the program will be completely self-supporting. In actuality, due to federal budget decreases, the government portion of the funding has been severely decreased so that the program must become self-supporting by year three instead of by year five as originally planned.

This WPI-industry program is now entering its second year. The NSF contribution was $100,000 for year one with expectations for $100,000 for year two. The industrial contributions have been $10,000 for each of three firms for year one, and $15,000 for each of six firms for year two.

Each firm may propose a project in the field of advanced automation. A Board, consisting of faculty and company represtatives and the Program Director, then approve or disapprove the project proposal. Projects include the use of desk-top computers, the application of robotics, or the application of scanning techniques. For each project the company receives some time of a Ph.D. faculty member plus a team of graduate and undergraduate students to perform the analyses. The university researchers and the company representatives work closely together. Finally, the industry generally has the immediate and short-run perspective while the university team provides the broader and somewhat longer-term perspectives. The program is working well to date and is expected to continue in spite of the declining government funding.

5. Hoechst-Harvard Program on Molecular Biology

Perhaps the largest collaborative arrangement between a company and an academic institution is the recently completed agreement between the West German pharmaceutical company Hoechst and Massachusetts General Hospital (the teaching hospital for Harvard University). The amount will be $50 million and the research will be on molecular biology. Mass. General will allow faculty full academic freedom without regard for commercial implications. When anything patentable is generated, Hoechst will have to act fast to patent it before it is published. Similar to the WPI-Emhart program, the company, Hoechst, has the right to train its own scientists in the university's laboratories.

6. DuPont-Harvard Program in Genetics

The DuPont Company is giving Harvard Medical School $6 million to support research in genetics. This work will involve gene-splicing, allowing scientists to isolate genes for biologically important proteins. The company will be given exclusive license to market patentable products or processes that result. Harvard will maintain the patents. The new grant equals nearly half of Harvard Medical School's annual tuition and endowment income.

7. Other Programs

Ten companies are contributing $7.5 million for a new computer center at Stanford University. Similarly, Control Data, Burroughs, and Minnesota Mining are investing $5 million for computer research at the University of Minnesota. Corporations, in general, support 10 percent of all research at MIT, and 5 percent of all research at Stanford University. Across all United States universities, approximately three and one-half percent of research is funded by industry.

III. DISCUSSION

The matrix presented in Table 1 catalogues the potential needs and confliects which exist between universities and industry.

a. *Rewards*

Although university rewards for faculty are supposed to be based on teaching, service, and publications, in most cases publications remain as a major source of reward. This is changing slightly although highly prestigious, research-oriented, United States universities, still reward largely on the basis of publications. Most faculty promotion and tenure committees consider

TABLE 1: University-Industry Issues Matrix

	Issue	*University Issue*	*Industry Issue*
a.	*Rewards*	*Based on publications*	*Based on profit*
b.	*Orientation toward Time*	*Long*	*Short*
c.	*Research Direction*	*Based on scientific curiosity*	*Based on need for results directed at current problems*
d.	*Peer Group Loyalty*	*External*	*Internal*
e.	*Departmental Structure and Autonomy*	*Low Structure, High Autonomy*	*High Structure Low Autonomy*
f.	*Risk*	*Highly Risky (basic research)*	*Less Risky (project oriented)*
g.	*Communication*	*Open*	*Confidential*

this criteria paramount. On the other hand, industry generally does not base promotion decisions on publications but rather on an employee's contribution to profit. Therefore, we see the faculty person trying to publish his research findings without delay while his industrial partner is focusing on profit.

b. Orientation toward Time

In general, university faculty are oriented toward long-time horizons compared to their industrial counterparts. For example, a faculty person usually has teaching and service responsibilities in addition to research; therefore, although some data gathering might take place during the academic year, the major research often takes place during the summer months when teaching commitments are at a minimal. This, of course, varies with "release time" but the point is that the urgency for results is often less present among university faculty than among industrial researchers. As a further example, a faculty hiring decision is often made a year or more in advance of reporting for teaching and research, and we all know that Ph.D. dissertations (where much research is done) often take three years or more. There are, of course, exceptions to this dichotomy toward time orientation but in general we feel it does apply and is an issue that should be recognized.

c. Research Direction

University faculty generally focus their direction based on scientific curiosity and on their independent decisions and interests. On the other hand, industry researchers usually focus on current problems of immediate concern and within the general purview of the company. Of course there are exceptions to these generalizations, but we believe they usually apply. Industrial research is more highly focused with teams of researchers often concentrating on very specific problems. The academic researcher may occasionally work on a small team but more often works independently and follows directions of his interest with less concern for immediate results.

d. Peer Group Loyalty

This issue is one of the most difficult to dichotomize but, nevertheless, is one of great importance. In general, the university faculty person feels some internal loyalty to his university but often feels loyalty to a constituency of peers beyond his own university. His professional recognition is often based on peer evaluation throughout the country and abroad. On the other hand, the industrial scientist is usually evaluated within his own organization and his peer group loyalty is generally within the organization rather than beyond.

e. Departmental Structure and Autonomy

The university person probably has more individual autonomy and less departmental structure than persons in almost any other economic pursuit. This is indeed often the factor cited by university persons as the most attractive part of their profession. On the contrary, industrial researchers are often organized in a highly structured way with regular reporting requirements and relatively low autonomy when compared to their academic counterparts.

f. Risk

The various elements listed above are not independent of each other. Indeed, it is the lower structure and higher autonomy of the previous element (e) that allows the university researcher to embark on relatively risky projects of basic research. A university researcher could spend several years on a certain research path and, when he is convinced that the path is not a sound approach, simply change direction. This is much less true for the industrial researcher who must show results in a short period of time. Therefore, he will generally opt for a more conservative approach to research with a greater chance of success in a short period of time, but with, perhaps, a less significant result.

g. Communication

The university person is trained not only as a researcher but as a teacher as well. His communication is open without limitation among peers, through Ph.D. students he is training, and in regular classroom teaching. He enjoys the open communication and, as mentioned previously, is encouraged to broadly publish and share his ideas and findings. The industrial person must often be more guarded in sharing or communicating his findings since this information may well be responsible for future corporate profits.

These issues are not meant to discourage industrial-university cooperation but rather to have the reader become aware of the many difficulties that do exist. There is increasing recognition that companies and the academic world have much to gain from mutual endeavors. M. E. Pruitt, former Vice President for Research and Development at Dow Chemical, stated, "I believe academic researchers can get involved with industry without losing their academic freedom" (6).

On the other hand, David F. Noble, who teaches History of Technology at MIT, and Nancy E. Pfund, Research Associate at Stanford Medical School, warn of businessmen's attempts to take advantage of university-based experts:

> *With industrial support the primary consideration guiding university funding is not social need but rather the profit needs of the firm itself. Moreover, the firm in purchasing*

> *access to the university's resources, is blocking access to others and has no oblication to share that access...and the industry is getting far more than it is paying for: it is getting the cumulative social investment—one that took decades and sometimes centuries to create—in return for little more than operating expenses.* [For example, Monsanto's agreement with Harvard, they argue]...*has in essence transformed a part of a public-sector social resource into a private-sector preserve, with little public scrutiny or accountability over its use.* (8)

IV. SUMMARY

In spite of the difficulties described in the previous section, let us remember that in the past few years many university-industry projects in the United States have been started and show promise of producing positive results. Areas of commonality from our examples include:

1. Universities are able to patent their findings while the supporting companies receive royalty-free licenses.
2. University researchers must receive enough release time so that at least fifty percent of their efforts can be directed toward a particular cooperative project.
3. Projects are guided by small, joint committees consisting of members from the sponsoring firm(s) and from the university.
4. Faculty must be free to publish findings, perhaps with a short review time allowed the firm to assure that no confidential information is divulged.
5. In the case of multi-company sponsors, the project selections are particularly pertinent so that areas of commonality can be found and a multiplier effect achieved.

6. At the working level, selected faculty and industry counterparts must be able to develop a person-to-person relationship beyond the two institutional commitments.

Questions to be addressed in the future include:

What is the effect of competing companies supporting research at the same institution?

Will the new industrial ties warp the direction of university research?

Are specific companies taking advantage of discoveries made possible through previous government (public) funds?

How will the new industrial support affect scientific and public communication of the results over the long run?

The recent efforts to bind industrial and academic research more strongly is still largely in the experimental stage. It remains to be seen whether the advantages outweigh the disadvantages, but, in this day and age of rapid scientific and technological change, these collaborative efforts are worthy of note and may become a potent force.

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