Forging Links Between Engineering Education and Industry: The Research Connection

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The mutual needs of society, industry and universities are creating opportunities for closer ties between industry and academia. Many new, and old, forms of university-industry collaboration are emerging or re-emerging, particularly in the area of research. Yet the views of engineering faculty on these issues have received scant attention as these important changes are taking place. In this paper, we report the results from a survey of a national probability sample of engineering faculty on several aspects of industry involvement in the academic research enterprise.

Background

The demise of the Cold War, concern over cutbacks in federal funding for university research, public calls-for more accountability in the outcomes of research, global challenges to U.S. competitiveness, and the scaling back of industry R&D budgets all have brought the relationship between industry and universities into new focus.[1-3] While federal funding has been the largest driver of academic engineering research, the historical relations between universities and industry have played an important role in the development of technology in many industries and the development of many engineering fields.[4] As these new challenges begin to reshape these historical relationships, many policy-relevant questions are emerging about the role of industry in university research. A recent 1995 National Academy of Engineering report recommended that “universities and companies commit themselves to relationships that couple industrial technology and practices with the leading edge of research and advanced education in engineering” as a way of enhancing the nation’s social well-being, our industrial competitiveness and the quality of our technical talent pool.[5]

Much discussion and debate has taken place among public policy scholars, university administrators, government policy-makers and students of science, technology and education policy over the proper role of industry in higher education. Noticeably absent has been the voice of engineering faculty on these industry-university linkages. While most data used in these debates consist of macro-level input indicators, such as aggregated research expenditures, enrollments, and the like, some work is beginning to emerge from the micro-level point of view. Rahm[G] recently studied the technology transfer process from universities to industry from the perspectives of faculty and university administrators. Recent studies of university organized research centers, including National Science Foundation (NSF)-funded Engineering Research Centers (ERCs), have also collected data from participating faculty and administrators.[7,8] Lee has completed a national survey of faculty in several science, engineering and social science disciplines on the roles academics play in economic development and industrial innovation.[9] Slaughter and Campbell have investigated the perceptions of scientists and administrators on the benefits, conflicts and mechanisms of industry-university collaboration.[10] While many of these studies are case studies, are based on select groups (e.g., chairs, ERC directors, etc.), or use samples of faculty primarily in the sciences or at research-intensive ‘ universities, there-is no work-based on a generalizable sample of engineering faculty across most of the engineering schools in the U.S. Indeed, these are the “working faculty” that are crucial to any kind of successful university-industry partnership.

In this paper, we discuss the findings from a survey of a national probability sample of engineering faculty on four important issues related to industry-university relationships: (1) the extent of industry support for academic engineering research, and the extent of faculty support for increased industry involvement, **(2) the** changing nature of the relationships between industry and university research, **(3)** the nature and characteristics of industry-sponsored engineering research in U. S. universities, **(4)** the role of industry sponsored research in engineering education and the perceived benefits to students of their involvement in industry-sponsored research.

Methodology

A national mail survey of engineering faculty was conducted in 1993 by the Center for Technology Assessment and Policy at Washington University in St. Louis, with support from NSF. Using as a base the 200 institutions with the highest ASEE reported research expenditures,[11] a sampling frame of faculty was constructed from university catalogue listings. Included were faculty who satisfied all four of the following criteria: (1) full-time faculty, (2) tenured or tenure-track faculty, (3) faculty whose principal appointments were in engineering, and (4) faculty who were currently or had been engaged in university-based engineering research during their careers. A probability target sample based on the first three criteria above, stratified by institutional research intensity (as measured by research expenditures) and governance (public or private), of 3,534 engineering faculty was selected to receive a mail questionnaire. Of those, based on the screening questions on the questionnaire and extensive telephone follow-up contacts, 2,829 faculty met all four criteria for inclusion in the survey. A total of 1,727 usable questionnaires were received, for a response rate of 61%.[12]

Our sample of engineering faculty had been engaged in university-based engineering research for an average of 15.1 years prior to the survey and had an average age of just over 47 years. The sample was 95.4% male and 4.6% female. Almost two-thirds (63.3%) were born in the U.S. By ethnic group, the sample was 79°/0 Caucasian, 17°/0 Asian or Pacific Islander, 2.30/0 Hispanic, 1.30/0 Black and O. 4°/0 American Indian or Alaskan Native. Over half (56.1%) of the sample were Professors, just over a quarter (28.8%) were Associate Professors and 15. 10/0 were Assistant Professors. The respondents covered a large number of engineering disciplines and had research specializations in a wide variety of broad application areas, from Information, Communication and Computation, to Bioengineering and Biotechnology, to Construction and Physical Infrastructure, to Energy, to Manufacturing and Materials. Finally, our stratified sampling procedure yielded an obtained sample with 34% from the 20 most research intensive schools (stratum 1) that account for over half of all research expenditures, 20°/0 from the next stratum of 30 schools, 230/0 from the next stratum of 50 schools and 22°/0 from the stratum containing the next 100 schools. While the strata in the population contain a more even distribution of faculty, the oversampling in the top stratum was designed to reflect the disproportionate amount of research activity in stratum 1 schools without neglecting faculty in the other strata.”

The questionnaire covered a range of topics related to university-based engineering research, including: the nature of the research; disciplines and fields of research; organization, funding levels, and sources of support; changes in research over the researchers' careers; involvement of industry and government in research; and involvement of students in and benefits from research activities. The tidings reported below focus on the industry-university research connection.

Findings

The Extent of Industry Involvement

Of the 1,632 faculty in our sample who were currently engaged in engineering research, over 80% report having one or more ongoing externally funded research projects, with an average research expenditure of $236,000 from July 1, 1992 to June 30, 1993. Dickens has reported that, based on NSF data, in 1991 industry contributed about seven percent of the total funding for R&Din all fields in U. S. universities. 13 In our own study, faculty data indicate that industry contributed about 17% of all funding to individual faculty for university-based engineering research and development in 1993 (the figure reaches 21% of external funding when internal university financial support is removed). [14] The higher percentage in our research reflects the logically higher percentage of support from industry to engineering, as contrasted to industry finding in fields of more basic "science." Over three-quarters (79%) of the faculty in our study also reported having received funding from industry sometime during their stay at their current university. What is apparent is that industry funding currently comprises a significant part of research funding in engineering and that most engineering faculty have been supported by industry sometime during their university careers.

It is often said that strong university-industry collaboration requires faculty that understand industrial products and markets and faculty that have working ties to industry. [15,16] The latter presumably enhances the former. In our sample, 64% of the engineering faculty had some Ml-time professional experience in industry (or government) prior to their current position; in fact, those faculty averaged almost six years of prior experience. Similarly, almost 88% said they had been a consultant to industry (or government) while they were a faculty member. Based on our sample, engineering faculty are likely to have the kinds of understanding of industrial needs that augur well for many forms of university-industry collaboration.

Questions are often raised about the attitudes of faculty toward industry involvement in university engineering research. On the one hand, concern over cutbacks in federal funding suggest the need for alternative sources (although industry is unlikely to make up the shortfall). On the other, questions about conflict between the fundamental values of universities and industrial firms sometimes nag at faculty (and, indeed we will have more to say on this issue later in this paper). Nonetheless, over three-fourths (79%) of our faculty respondents would like to see more industry involvement in academic engineering research, while only 6°A would like to see less. While the federal government is clearly the most desired source of research support (81'XO said it was their first or second choice), over half the faculty (56%) said support from industry was their first or second most desired source of research support, far outstripping any other non-federal source.

Changes in Industry Involvement

The extent of industry involvement in academic engineering research is substantial. But, how has that involvement changed over time? The results discussed below are based on faculty perceptions of the changes that have occurred since they began doing research at their current universities. *[7]

Faculty in our sample have an average of 13 years experience in research at their current universities. The perceptions of faculty are divided on whether there is now more industry financial support for university-based engineering research than in the past: 38°/0 say there is now more industry funding, 28°/0 say the level is about the same as when they began their research, and 23% say there is less financial support now.- Faculty are similarly divided on whether there has been a change in the number of personnel exchanged between industry and universities and whether there is now more access by university personnel to industry equipment and facilities. A bit more consensus exists on whether restrictions by industrial sponsors on the dissemination of research output has changed: about a third (30%) say such restrictions are more common now while almost two-thirds (63%) say it is about the same as it was when they began doing university research. Very few thought there were now fewer restrictions from industry on dissemination of research results. More than half of our respondents (550/0) do say, however, that industry influence over areas chosen for research and demands for short-term deliverables from the academic research supported by industry has increased; just over four in ten think little change over time has occurred in these areas. Almost no one sees a decrease in industry influence over the areas of research or fewer demands for short-term deliverables.

Nature of the Research and Research 0utputs[18]

We have reported elsewhere that engineering faculty in our sample believe that academic engineering research is becoming more applied and industry-relevant.[19] What we want to look at in this section is the nature of engineering research that is heavily funded by industry as contrasted with the nature of engineering research funded by other sources, most notably, federal sources. Does high industry involvement affect the nature of the research? In order to approach this question, we have subset our sample into two smaller "extreme case" groups: (1) those who were currently receiving 50% or more of their funding from federal government sources and 10% or less from industry (N=626) and (2) those receiving 30% or more of their funding from industry and 10% or less from federal funds (N=141). In the analyses which follow, the former group is called 'High Federal Support" whereas the latter is called "High Industry Support''.[20] Comparison of these two groups can provide information on the effects of source of support on the nature and characteristics of the research.

We begin by looking at the organization of research based on the source of support. High industry support is associated with research that is conducted by collaborating investigators in large research groups (more than seven people) more often than is research funded with high federal support (21% vs. 10%). Conversely, high federal support is somewhat more likely to support individual principal investigators with a few staff members (59%) compared with high industry support (50%). There were no significant differences by finding source for whether the researcher was involved in an organized research unit (i.e., a formal Center, Institute, Laboratory, an so on). This was somewhat surprising given that almost half our sample were participants in an organized engineering research unit and given the higher levels of industry finding associated with organized research units.[21]

The average number of research grants awarded to researchers in 1992 and 1993 did not diner by major source of tiding. The average duration of research grants, however, did differ depending on whether the primary funding source was industry or the federal government. In particular, faculty with high industry support were more likely than those with high federal support to receive grants for less than six months duration (34°/0 vs. 14°/0) and for durations of six to 12 months (73°/0 vs. 5 10/O). Conversely, those , with predominantly federal funding were more likely to receive grants of 19 months to two years duration

(26% vs. 16%} and grants for more than two years (51% vs. 21%). Clearly, research grants of shorter duration are more associatedwith industry funding for engineering research. This is consistent with the faculty's views (discussed earlier) of the importance of short-term deliverables from industry-sponsored research.

Table 1 below shows an interesting pattern in the distribution of research effort on the Basic <--> Applied <--> Development continuum Respondents were asked to approximate the percentage of time they spend on R&D activity in basic research, applied research and development (all of which were defined using the standard NSF definitions). Faculty with high industry support are engaged in more applied research and, especially, more development work than are those with high federal support. High federal support appears to drive more basic research among engineering faculty. Clearly, the basic vs. more applied focus is affected by industry funding.

Table 1: Average Percentage of Time Spent on Basic Research, Applied Research and Development, By Source of Support

	High Industry		High Federal	
	%	N	%	N
Basic Research	16.8	(140)	38.2	(624)
Applied Research	54.0	(140)	47.3	(624)
Development	29.3	(140)	14.4	(624)

All contrasts significant at $p < .01$

Respondents were asked to characterize their research on a number of bipolar, "adjective anchored" dimensions that help us better understand the nature of the research. For example, one such dimension was an Experimental-Theoretical dimension. Faculty were asked to place their research along a five-point continuum from Theoretical at one end to Experimental at the other. Consistent with the Basic Research vs. Applied Research/Development dichotomy discussed above, high industry support was associated with research that, relative to high federal support, was significantly more experimental than theoretical, more synthesis than analysis, more oriented to product and process outputs than to publications, less long-term focused, and more pulled by the market than pushed by science and technology. There was no difference by source of support in the degree to which the research was team-oriented, the extent of student involvement (more on this later), the degree to which the research was driven by funding agency or investigator interests, nor whether the research was problem- or methodology-driven.

How important are various outputs of research to faculty who are supported by industry or government sources? Obviously, this is partly a function of the nature of the research, which we have seen is more applied for those with high industry support. Table 2 shows the contrasts in the percentages saying a particular outcome of research is important or extremely important by source of support. Consistent with the more applied nature of the research supported by industry, commercial products and processes, hardware, licenses, patents, and invention disclosures are more important outputs to faculty with high industry support than to researchers with high federal support. While almost all faculty in our sample are likely to think conference presentations and published papers are important outcomes of research, they are somewhat less important to those with high industry support for their research.

Table 2: Percentages Reporting Output as Important or Extremely Important, By Source of Support

Research Output	High Industry %	High Industry N	High Federal %	High Federal N	p <
Hardware	38.7	(137)	25.8	(597)	.01
Computer Program	44.6	(139)	43.5	(602)	--
Algorithm	43.4	(136)	46.4	(597)	..
Commercial Product	30.4	(138)	16.7	(600)	.01
Military Product	4.7	(137)	7.7	(600)	--
Patent	18.1	(138)	12.1	(606)	.10
Invention Disclosure	17.7	(136)	11.5	(598)	.05
License	18.3	(137)	8.7	(598)	.01
Book/Monograph	19.6	(138)	23.4	(602)	--
Commercial Process	34.3	(137)	16.6	(590)	.01
Published paper	75.5	(139)	88.9	(611)	.01
Conference paper/presentation	65.2	(138)	73.2	(611)	.10
Technical report	51.5	(138)	45.7	(606)	--
Theses/dissertations	80.4	(138)	82.9	(608)	--

The focus of engineering research was also investigated in our study. Engineering faculty with high industry support are significantly more likely than those with low levels of industry support to say their research involves improving manufacturing systems and methods (33 °/0 vs. 170/0), developing applications for specific industries or technologies (60% vs. 32%), and investigating quality assurance and control methods (18% vs. 8%). On the other hand, consistent with our previous findings, those faculty with high federal support are almost twice as likely (49% vs. 25%) to say their research adds theoretical knowledge to a large or very great extent. Finally, related to these particular outcomes, engineering faculty also were asked if any of their research had led to a major development adopted by industry or government. Almost half (45%) of those with high industry support compared with 33% of those with low industry support said their research had led to a major development in industry or government.

Finally, faculty were asked to identify problems that they face as engineering researchers and specify their most pressing problems. Source of research support had no impact on the perceptions of engineering faculty concerning the most important problems they faced: excessive time required to obtain and sustain research support, lack of funding, inconsistency and instability of tiding, and shortage of time to conduct research. Nonetheless, industry supported researchers were less concerned about the high cost of doing research (29°/0 vs. 38°/0) but were more likely to think a shortage of good students was a problem (66°/0 vs. 58Yo) and were substantially more likely to cite lack of funding for research they "really want to do" as a problem (50% vs. 36% for researchers with high government support). This last finding is consistent with our earlier finding that most faculty think the influence of industry over the areas chosen for research has increased since they began doing engineering research in their universities.

Industry Research Support and Student Education

Student involvement is reported to be extremely high in the research reported by our faculty sample: 95% of the faculty report that graduate students are involved somewhat or to a great extent in their research and 47% report some or a great extent of undergraduate involvement. While almost all faculty report involvement of graduate students in their research, high federal support is associated with slightly higher levels of graduate student involvement (97%) than is high industry supported research (93%); although statistically significant, the magnitude of the differences is trivial. No difference is found for undergraduate student involvement.

High industry support and high federal support are associated with approximately the same number of graduate students supervised per faculty member (around 5), but, high industry-supported-faculty supervise more master's students (2. 8 vs. 2.1) while high federal support for faculty research appears to support more doctoral students (3. 1 vs. 2.1). There was virtually no difference by source of support in the roles students filled in sponsored research: undergraduates were most likely to be used as "research assistants" and graduate students were most often in the role of "associate researchers" or "independent researchers. "

We have seen that faculty with different primary sources of research support do somewhat different kinds of research, are oriented to different outputs, and organize the research in slightly different ways. Yet, there is very little difference in the extent and nature of student involvement in these different kinds of research. Are there, however, different benefits to students of involvement in more industry-sponsored research? Faculty with high and low industry supported research are equally likely to say that research to a large or very great extent helps students acquire specialized knowledge (94%), acquire problem-solving skills (920A), acquire maturity and confidence as an independent researcher (88%), and improve their communication skills (74%). Faculty with high federal research support are slightly more likely than those with high industry support to say that research involvement helps students acquire fundamental research skills (93% vs. 88%), utilize cutting-edge technologies (63% vs. 55 %), gain cross-disciplinary research experience (50% vs. 37%), and, not surprisingly, interact with government researchers (19% vs. 5%). As expected, faculty with high industry support are more likely to say research involvement leads students to a better understanding of real-world industrial problems(61'XO vs. 33%) and gives them opportunities to interact with industry researchers (44% vs. 13 %).

Do the opinions of faculty regarding the research-oriented job prospects for doctoral students differ depending on whether their research is more industry supported or more federally funded? Research-oriented job prospects in the private sector are rated similarly by both groups of researchers: research-oriented job prospects in big companies were rated good to excellent by 58'% of these faculty, in small companies by 47% of the faculty, and in consulting by 42%. There also was no difference by source of funding in faculty attitudes toward job prospects in university faculty positions: 48% thought such prospects were good to excellent for their students. Those researchers supported largely by federal funds were more likely to rate the prospects for research-oriented positions in government as good to excellent (54%) than were researchers with high industry support (390/0). Similarly, those with high federal support were more likely to think prospects for non-faculty research positions in universities were good to excellent (66%) than were faculty with high industry support (55%). [It should be mentioned that all of these perceptions of the job prospects of the faculty member's doctoral students in 1993 are more positive than the generally pessimistic discussions going on currently on the general research-oriented job prospects for doctoral students.]

Summary and Discussion

Results from a national survey of engineering faculty paint a fairly consistent picture of the extent of industry involvement in academic engineering research and the effects of that involvement on research outputs and on students' education. Industry is currently an important source of support for engineering research, many faculty have substantial experience with industry, through prior work experiences or consulting, and most faculty desire more industry evolvement in academic engineering research. Nonetheless, based on our findings, increased industry involvement is likely to bring real changes to the academic engineering research enterprise and raises significant questions that university administrators and faculty must grapple with.

The Tilt Toward More Applied Research and Development: Industry supported research clearly brings with it research tilted toward the applied research and development end of the R&D spectrum, and, as a consequence, less emphasis on theoretical work and basic engineering research.[22] What is the proper mix of academic engineering research activity, and corporate R&D activity, for optimal economic growth and university research excellence? It has been suggested that such a "tilt" might be beneficial to economic progress and to the relevance of academic engineering research to social needs. On the other hand, it is argued that more broad, basic academic research has been the historical contribution of universities that has driven technological advances in many fields. In light of the virtual abandonment of basic research by industry, is the basic research mission of the university even more important for the future? Or, just how far should university engineering go in pushing its research downstream into design, production and marketing? Tighter industry R&D budgets will make it inevitable that future industry finding will go to those university research projects with a high probability of contributing to corporate programs and strategies.

Industry Influence on the Process of Research: One of the clear themes in our findings is the increasing influence of industry involvement on a number of dimensions of the research process. First, engineering faculty report increasing influence of industry on the areas and topics chosen for research at the expense of the desires of faculty researchers themselves. Second, research funding from industry is increasingly of relatively short duration. Third, demands for short-term deliverables from industry-supported research are increasing. Faculty are already greatly concerned about the lack of time to conduct research and the time required to obtain and sustain research support. And, faculty with high industry support in our survey were particularly concerned about the lack of money for research they really wanted to do.

These problems are likely to be exacerbated with short-term research projects, involving more reporting requirements, and more faculty energy spent "following the industry dollars. " In addition, the relative de-emphasis of long-term research (be it basic or applied) may have dysfunctional consequences on the establishment of sustained "research programs," on research that deals with issues of great technical complexity, on the institutional stability of talented research support personnel, and on the long-run education of students.

Industry Conflicts with Basic University Values: A somewhat naive argument is sometimes made that industry influence over the areas chosen for academic research is tantamount to limiting the academic freedom of faculty researchers. The same case can quite clearly be made against all sources of external tiding, especially in an era when the expectation that research should lead to better social or economic well-being has been elevated to a moral imperative. In fact, constraints on the academic freedom of researchers are more pervasive, if not more subtle, from other forces. First, "... the cost and complexity of efforts necessary to advance the frontier restrict the "freedom" of university researchers to select their research programs, pursue their curiosity, or follow the dynamics of a fast-moving field. "2[3] Second, the very financial pressures that many universities are feeling are putting enormous pressures on many faculty to "enhance the revenue stream. " For researchers, this often translates into more cost recovery for the university from external research funds or limiting internal funds in support of research. Market forces within the science and engineering disciplines, notably the increased competition for faculty positions, external grants, and tenure, force constraints on the 'freedom" of engineering faculty to pursue their ideas unfettered by other considerations.

The point is that industry funding for academic engineering research brings its own set of constraints into a world in which constraints abound. On the other hand, the increased restrictions that engineering faculty perceive concerning the dissemination of research results does indeed run headlong into a sacrosanct university value: the free dissemination and transmission of knowledge, which undergirds the basic education mission of universities. The free flow of ideas is one of the fundamental characteristics of institutions of higher education and mechanisms of prior review, veto power over publications and presentations, the proprietary nature of much industry-sponsored research, and other intellectual property rights issues might well compromise the free flow of ideas from engineering research.[24]

The Value Conflicts Over Research Outputs: Clearly, industry-supported research elevates the importance of commercially-valuable outputs: products and processes, licenses, patents, invention disclosures, hardware and the like. Although bringing in research grants and contracts has long been a significant factor in the advancement of engineering faculty, this activity has taken place within the traditional academic reward structure which places a high premium on peer reviewed research publications as the measure of academic success. And, although administrators in many institutions increasingly value research outputs that add to the institution's revenue stream (witness the rise of the university technology liaison offices and the explosion in university patenting in recent years), it is likely that faculty continue to be rewarded in salary increases, tenure and promotion within the institution for more traditional outputs, mainly, publications, as opposed to patents, products or processes. Will the university reward system adjust to the realities of the commercialization expectations of industry-sponsored research? Should it? What affect will this have on the quality of research, the stability of the faculty, and the ultimate educational mission of universities?

Trade-offs in Student Research Experiences: More-industry-supported research involves students to the same extent, and in the same roles, as less-industry-supported research, and generally offers the same skill-development and educational benefits as less-industry-supported research, although some tradeoffs are inevitable. The generally shorter duration of industry-supported projects, many less than six months, might partially account for our finding that industry-supported research utilized fewer doctoral students and more master's students than did less-industry-supported research. It is also apparent from some of the results that faculty are suggesting that federally-supported research is somewhat more likely than industry-supported research to help students gain fundamental research skills, involve them with cutting edge technologies, and help them develop broader cross-disciplinary knowledge. On the other hand, industry-supported research is believed to give students better understanding of real-world industrial problems and expose them to industry researchers. Evaluating the trade-offs will involve a detailed assessment of the job market, and requisite research-related skills needed in the future.

Kash and Willenbrock, among others, argue that "more engineers with today's research-oriented training are not the country's primary need. Instead, it will be more practice-oriented engineers.. ."[25] In fact, their-call for more practice-oriented master's programs and more emphasis in doctoral education on the requirements of commercial technology suggest the benefits of industry-supported research experiences. If downsizing of the academic engineering enterprise occurs in the near future, there will be less demand for academically-qualified doctoral graduates in faculty positions, again suggesting that even more graduate engineering students must be prepared to be absorbed into the industrial sector. In fact, while the data are less than definitive, there is some evidence that recent doctoral students already are finding fewer academic jobs and are finding the transition to other types of jobs extremely difficult.[26] Suffice it to say that concern over the future of doctoral education in engineering is at a fever pitch and changes in the support structure of research will impact substantially the future direction of such programs.

Endnotes

1. **Council** of Economic Advisors, "Supporting Research and Development to Promote Economic Growth: The Federal Government's Role," Washington, DC, October, 1995.

2. National Academy of Engineering (NAE), Forces Shaping the U. S. Academic Engineering Research Enterprise, Washington, DC: National Academy Press, 1995.

3. -Herbert I. Fusfeld, Industry's Future: Changing Patterns of Industrial Research, Washington, DC: American Chemical Society, 1994.

4. Nathan Rosenberg and Richard Nelson, "American Universities and Technical Advance in Industry," Research Policy, vol. 23, (1994), 323-348.

5. National Academy of Engineering (NAE), *op. cit.,* p. 12.

6. Dianne Rahm, "U. S. Universities and Technology Transfer: Perspectives of Academic Administrators and Researchers," Industry and Higher Education, June 1994, 72-78.

7. Wesley Cohen, Richard Florida and W. Richard Gee, "University-Industry Research Centers in the United States," Carnegie-Mellon University, July 1994.

8. A study underway by the Division of Education and Centers, Directorate of Engineering, National Science Foundation is looking at the 21 NSF-sponsored, university-based Engineering Research Centers from the multiple perspectives of administrators, sponsors, and graduates who were involved in these ERCs.

9. Yong S. Lee, "Technology Transfer and the Research University: Drawing the Boundaries of University-Industry Collaboration," paper presented at the 1995 Conference of the American Association for the Advancement of Science, Atlanta, February 1995.

10. Teresa Campbell and Sheila Slaughter, "Protecting the Public's Trust: A Search for a Balance Among Benefits and Conflicts in University Industry Relationships," Final Technical Report to the National Science Foundation, Center for Higher Education, University of Arizona, 1995.

11. -The primary source of data on research expenditures was American Society of Engineering Education (ASEE), Engineering Education 81, Vol. 2, 1991.

12. Sampling methodology is described in great detail in Nirmala Kannankutty, Engineering Research in U.S. Higher Education: Survey Sample Development and Implementation, Center for Technology Assessment and Policy (Report 95- 1), Washington University, St. Louis, March 1995.

13. Charles Dickens, "The Academic Engineering Research Enterprise: Status and Trends," pp. 69-132 in National Academy of Engineering (NAE), Forces Shaping the U. S. Academic Engineering Research Enterprise, Washington, DC: National Academy Press, 1995.

14. A companion national survey o f651 university-based organized research unit directors showed that 24.9% of their units' funds came from industry (cf 17.4% in our faculty study). See Robert Morgan, Donald Strickland, Nirmala Kannankutty and Carol Spelman, "Engineering Research in U. S. Universities: How University-Based Research Directors See It," pp. 251-256 in Proceedings of the Frontiers in Education 23rd Annual Conference, L.P. Grayson (cd.), November 1993.

15. John Armstrong, "What Should Industry Expect from Academic Engineering Research," pp. 59-68 in National Academy of Engineering (NAE), Forces Shaping the U. S. Academic Engineering Research Enterprise, Washington, DC: National Academy Press, 1995.

16. Chang-Lin Tien, "Reengineering the Academic Engineering Enterprise," pp. 37-46 in National Academy of Engineering (NAE), Forces Shaping the U. S. Academic Engieering Research Enterprise, Washington, DC: National Academy Press, 1995.

17. A more fine grained analysis of change based on constructing cohorts with various years of experience and examining the experience of change by cohort corroborated the more aggregate findings presented in this paper.

18. Where tables are not presented to conserve space, the differences discussed in the following section are significant at $p < .05$, and the vast majority are significant at $p < .01$. In all cases, a X^2 test of independence, a difference of proportions test, or a difference of means test, as appropriate, was used to identify significant inter-group differences.

19. See Robert Morgan, Donald Strickland, Nirmala Kannankutty and Joy Grillon, "Engineering Research in U. S. Universities: How Engineering Faculty View It," pp. 1506-1514 in Proceedings of the 1994 Annual Conference. American Society for Engineering Education, Edmonton, Canada, 1994.

20. Most industry-supported faculty in our sample had multiple sources of support, thus, making it impossible to identfy a significantly large number of cases with "pure" industry funding. This classification scheme was chosen to balance the need for sufficient numbers in each group to make

analysis feasible and the need to create conceptually distinct groups of faculty based on sources of support.

21. See note 14.

22. See the statement of the National Science Board for an excellent discussion of the distinction between basic research in engineering and basic science research. National Science Board, The Competitive Strength of U.S. Industrial Science and Technology: Strategic Issues, Washington, DC, 1992.

23. Fusfeld, *op. cit.,* p. 186.

24. **In our** parallel study of university-based engineering research units, the directors of research units with significant industrial support suggest that conflicts over intellectual property rights are not uncommon. See note 20 above.

25. Don Kash and F. Karl Willenbrock, "Engineering Education for the Workers of the Future," Issues in Science and Technology, Summer 1992, p. 30.

26. Committee on Science, Engineering and Public Policy of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, Reshaping Graduate Education of Scientists and Engineers, National Academy Press, Washington, DC, 1995; Raymond Greene, Barry Hardy and Steven Smith, "Graduate Education: Adapting to Current Realities," Issues in Science and Technology, Winter 1995-96, pp. 59-66.

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