THE IMPACT OF MICROELECTRONIC AND INFORMATION SCIENCES: A STUDY

Providing for and strengthening
a sustaining intellectual and
economic environment in engineering
and in computer sciences

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PREFACE

This study makes the assumption that the strengthening of the intellectual framework and the expansion of educational capacity in engineering and in computer sciences is inextricably linked with the stuff of national prosperity. Where but in American industrial technology can prosperity be assured.

Observing the conditions that must be in agreement to ensure prosperity, it finds a breach in the foundation. In the economic backwash, one finds evidence of regression in the pace of engineering advances, together with significant indications of an adverse ripple effect on U.S. engineering schools.

The analysis focuses on faculty members leaving universities, sharply falling doctoral degree activity and general erosion of graduate study. A significant slowing in the pool of qualified and interested graduate study candidates gives pause; it is a large enough problem that it cannot be dismissed. The economic and educational effects are clear. Graduate level research will be stalled, technological development will slacken, programs will be smaller, and the nation will find the interlocking conditions for prosperity severely out of tune.

Rapidly shifting markets, the demographics of a shrinking school age population, and deep seated economic and social circumstances create substantial strategic hurdles that must be counteracted to ease the drought of American scientific talent.

There are ways to counteract the negative economic effects of the talent drought and these are explored but the study finds we are a long way from home with no hopeful signs for a quick turnaround unless the nation moves in earnest to tilt its policies toward the joint resolution of these issues.

CENTER FOR MICROELECTRONIC AND INFORMATION SCIENCES

UNIVERSITY OF MINNESOTA

Providing for and strengthening a sustaining intellectual and economic environment in engineering and in computer sciences; expanding educational capacity

INTRODUCTION

The strength of the foundation on which a nation's prosperity rests is derived from four things: by the sophistication with which natural forces are transformed into life giving and life sustaining matter, by the grit of economic trade, and by the judicious application of the wealth that flows from this endeavor. Its enduring quality is influenced by the cultivation of knowledge and the way this finds expression in productive and creative enterprise that enhances our surroundings and opens up new opportunities to strengthen and improve the quality of the economic and social fabric. When these are in agreement, prosperity is assured.

Engineering and computer sciences have been primary forces in the creation of the industrial architecture vital to the strength of our economic base and in the creation of new technologies that have added to national prosperity. Microelectronic and Information Sciences (MEIS) have performed a central role in this development and are rapidly becoming an economic mainstay. MEIS represents the cutting edge of new and broad-based electronics technology by which its sponsors are uniquely positioned to provide a forceful response to the compelling needs of today, namely, industrial renewal and expansion together with productivity gains in areas of development, manufacturing, and production. Communication, data storage, data display, surface and interface sciences, manufacturing technology, and productivity efficient systems are encompassed by MEIS.

The educational role of MEIS is:

- Increase substantially the number of students graduated in M.S. and Ph.D.
- Exchange scientists between the university and industry
- Develop materials and programs for updating engineers
- Expose students to broad range of microelectronic and information science
- Strengthen intellectual framework by developing texts, handbooks, and courses

The purpose of this study is to review the background against which MEIS educational initiatives will be pursued; to describe the status of education in U.S. engineering and computer and information sciences; and to evaluate the effects of the MEIS educational program on expansion of educational capacity.

BACKGROUND

Signs of sluggish growth in the U.S. economy, a whale dragging at the stern of national prosperity, merit serious consideration commensurable with their importance to the free world's social and economic fabric. (Cf. lagging economic conditions, high interest rates, and deceleration of productivity growth*). In the economic backwash, we find indications of regression in the

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* "Non-farm business productivity growth declined from an annual rate of 2.77% in 1957-1968 to 1.89% in 1968-1973 and finally to 0.64% in 1973-1979." (Minneapolis Tribune, August 12, 1981, quoting Martin Baily in The Brookings Papers on Economic Activity.)

rate of U.S. engineering advances (Cf. with the increasing shift in the fraction of patent awards toward the Japanese, the Soviets, and the West Germans) together with evidence of a widening breach in the foundation on which engineering's strength rests. These developments merit consideration commensurable with their centrality to the strength of economic trade and to the future of U.S. scientific and technological leadership; they reflect structural weaknesses in the economics of American Science.

Caught in the financial squeeze, U.S. engineering schools are in serious trouble. The reasons include faculty attrition, a problem brought on by the drain of talent into industry and government as hard pressed faculty members pursue tangible financial and material support in the face of inflation; a dramatic decline in doctoral degree production, which is drying up the teaching pool even as it drains (engineering doctorates conferred plunged 33% from 1970-71 to 1977-78); and a concurrent decline of doctoral candidate scholastic and career interest in vital engineering disciplines such as Aerospace Engineering (down 47.0%), Chemical Engineering (down 36.2%), Civil Engineering (down 37.9%), Electrical Engineering (down 42.8%) and Mechanical Engineering (down 36.3%), the sharpest fall since . Contributing to the decline are rapidly shifting market conditions, the demographics of a shrinking school age population nationwide, and more troubling and deep seated social and economic circumstances.

FACULTY ATTRITION: DISINTEGRATION OF THE TEACHING NUCLEUS

According to the National Science Foundation and the Department of Education, there are severe shortages of qualified faculty members in most fields of engineering, as well as in the computer professions.[1] This has come about in recent years as industry has developed an increasingly sophisticated research and development capability to introduce new products and improved products. The lure of high salaries is chief among the reasons given for faculty terminations. Studies show that 10% to 15% of all engineering faculty positions in the U.S. today are unfilled; in certain areas, such as Solid State Electronics, Computer Engineering, and Digital Systems, the shortage is closer to 50%; and there is a slow but definite trend of established engineering faculty members leaving universities.[2]

The economic reasons for faculty departures are twofold. Chesson states:[3] "Uncle Sam pays better than industry and both pay more than university. In the order of government, industry, university, the median annual salaries are $29,300, $27,400, $26,400. Percents earning more than $31,00 were 41, 32, 22; percents earning less than $22,000 per year are 17, 21, 33." Chesson proceeds: "A big difference shows up in academic degrees, however. Clearly, university is not rewarding advanced degrees for R & D workers the way that government and industry do. With 69 percent of our university respondents holding Ph.D. degrees, compared to 29 and 27 percent for government and industry, the generally low pay scale is an indictment of academic emphasis on the earning power of higher education."

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1 Science and Engineering, Education for the 1980's and Beyond; National Science Foundation and the Department of Education; October 1980; p. 9.

2 "A Crisis in Electrical Engineering Manpower"; Stephen Kahne, National Science Foundation; IEEE Spectrum; June 1981.

3 Chesson, E., "The Future Shortage of Faculty: A Crisis in Engineering," Engineering Education, Vol. 70, No. 7, April 1980, pp. 731-738.

As a result, both engineering and computer science departments are suffering from multiple deprivation, a poverty of spirit created on the one hand by the mounting retreat and the accompanying diminishment of the intellectual and economic environment, and on the other hand by concurrent pressures characterized by expanded student faculty ratios, diminished opportunities for research, a decline in educational quality, and erosion of faculty salaries. These lackluster conditions have lead to a corollary erosion in institutional facilities and support; a matrix of laboratories, technical facilities and library resources that undergird the basic architecture by which a department perpetuates skills and expertise, the footing on which to attain the cultivation of knowledge. The fallout effect from disintegration of the faculty nucleus demonstrates the overwhelming importance of this aspect of the foundation on which engineering prosperity rests. Perpetuation of the skills and knowledge of established faculty members, the core of University, seems to be legitimately threatened by ill-advised actions.

A symptom of great change it is, a symptom of great progress it is not because its evolution has occurred with a disruptive rate of progression, a rapid transformation to which universities have been powerless to adapt, out of which severe displacement has occurred. Disruption has introduced disorder leaving a path of disquieting issues in its wake. Whether its course was capable of being plotted is a small matter; the disarray is as severe as that caused by a stormwind that scolded before it bit.

Largely determined by market forces, the shortage of qualified engineering faculty has received cautious national support as those in the wheelhouse of government have become totally preoccupied with budget and tax policy. In the meantime, these symptoms of ill-needed change needlessly persist. If it is reasonable to regard markets as instruments of thoughtful human enterprise, it is reasonable to assume that these market outcomes occur to ill-effect despite complex systems of human organization and not because of them. Therefore, it is well within our power as an advanced society to adjust market malfunctions to attain good effects because it is reasonable to assume that the corrective adjustment is a function of bidding up the quality and thus the value of the ideas on which market decisions are made.

Although it doesn't seem warranted today to say that academic engineering is the East Berlin of higher education, we have seen that engineering is not what it was and that people are getting out at a steady rate. It does seem safe to say it is no longer the center of things because the profit potential has disappeared for those who have attained or would attain the Ph.D. to enjoy both the profits of the mind and a decent living standard for themselves and their families. When this continues unabated over time, it poses the question as to whether it makes sense to believe this is temporary, for a miscalculation in this respect could cause lasting damage to American science. In the realization that things do not get better by being left alone, engineering deans cannot set aside the problem because the penalty for doing so would be most severe, namely an eventual shut down of affected programs.

It is a tangible and mounting problem of many dimensions with few opportunities for a quick turnaround, a crisis that could result in the nation drastically retarding technological advances. Unless the country tilts its policies toward the early resolution of the issue, one is compelled to believe that engineering strength will fall through the stools resulting in a further technological slowdown (both in absolute terms and in relation to America's trading competitors, notably the Japanese and the West Germans) and ultimately in another economic slowdown. Taken separately or together, these topics touch on the nation's capability to sustain the economic and social fabric and to maintain technological leadership for sustaining U.S. defense capabilities.

A number of important engineering sub-fields are threatened with academic extinction, according to Kravitz.[4] This poses the question as to the long-term capability of the nation to compete technologically, and to ensure the success of Federal initiatives to build up the nation's defense effort. Against this background, engineering faculty attrition becomes a centrally human situation affecting the success of new initiatives. At best, it presents itself as a major bottleneck. At worst, it could stall progress indefinitely, or place a cap on achievement because the defense industry today is experiencing a substantial shortage of engineers. In an assessment of economic trends, American Business[5] states, "In the Los Angeles area alone, defense industries reported a shortage of 30,000 aerospace and electrical engineers in 1979". We will buttress this finding in a subsequent section on engineering degree production and show conclusively that the substantial shortage of engineers occurred in 1979 because they were not in the college pipeline in sufficient quantity in prior years. The article concludes that "the education of

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4 Kravitz, Lawrence C., Talent for Technology: A Federal Program Manager's View; Can University-based Research Produce and Support the Personnel Needed to Maintain Technological Leadership?, Engineering Education; March, 1981: pp. 391-396.

5 "Summing Up: An Assessment of Economic Trends and Financial Moves", American Business, August 1981, p. 23.

new engineers could lag far behind the production requirements of the Administration's defense initiatives". As one can see, the issue of engineering integrity is one of grave consequence to the nation; it touches on the crucial affairs of state, namely the integrity of our social and economic institutions and the nation's security.

The essential difficulty is in the disintegrating scholarly nucleus around which the architecture of engineering education is structured. This break up poses a critical problem of how to preserve a sustaining scholarly environment that will perpetuate the tradition whereby engineering schools endow future generations of scholars with an esteemed body of faculty and an esteemed body of knowledge. Its existence depends on a qualified body of graduate students both dedicated and capable of assuming responsibility for the leadership of the engineering inheritance. Because of the disarray created by a turbulent economy, graduate engineering study is in mortal danger of failing to fulfill the vital function of scholarly endowment and stewardship, a risk-filled social venture because only a year of its effective absence would bring us within a hoe's width of a technological weed patch; the time has come when American science no longer explains the economy. The economy explains American science.

THE PLUNGING DOCTORAL AWARDS

If the reader appreciates the decline in engineering departmental strength, he will appreciate that U.S. graduate engineering work has gone through a decline in strength. The decade of the nineteen seventies marked a major turning point in U.S. engineering Ph.D. production. From 1970 to 1978, the number of doctorates conferred annually has plunged 32.9%, ending a year advance. Table 1, page 9, shows the figures falling year by year, for a group of twenty

TABLE 1
DOCTORATES AWARDED IN ENGINEERING & COMPUTER SCIENCES
UNITED STATES

Field Of Engineering	Academic Year (July 1-June 30)								Δ %
	AY 71	AY 72	AY 73	AY 74	AY 75	AY 76	AY 77	AY 78	AY 71-AY 78
Aerospace, Aeronautical, Astronautical Engineering	217	197	171	173	163	139	119	115	- 47.0%
Agricultural Engineering	55	65	70	45	52	33	21	37	- 32.7
Architectural Engineering	3	0	0	3	0	1	0	0	- 100.0
Bioengineering and Biomedical Engineering	29	46	54	43	55	58	47	61	+ 110.3
Ceramic Engineering	25	19	20	19	14	19	17	19	- 24.0
Chemical Engineering	406	394	397	400	346	308	291	259	- 36.2
Civil Construction and Transportation Engineering	446	415	397	368	356	370	309	277	- 37.9
Electrical, Electronics, Communications Engineering	879	824	791	705	701	649	566	503	- 42.8
Engineering, General	219	284	254	260	287	236	283	235	+ 7.3
Engineering Mechanics	148	147	127	157	123	77	81	78	- 47.3
Engineering Physics	26	30	9	21	25	55	38	37	+ 42.3
Engineering Technologies	1	15	19	4	2	2	3	3	+ 200.0
Environmental and Sanitary Engineering	49	41	41	59	55	49	52	36	- 26.5
Geological Engineering	9	17	4	14	7	3	6	0	- 100.0
Geophysical Engineering	1	7	10	7	11	0	3	1	0
Industrial and Management Engineering	139	168	130	146	119	121	104	118	- 15.1
Materials Engineering	78	96	116	94	97	118	133	114	+ 46.2
Mechanical Engineering	438	411	370	385	340	305	283	279	- 36.3
Metallurgical Engineering	148	127	125	119	99	72	54	75	- 49.3
Mining and Mineral Engineering	43	36	22	7	15	18	7	16	- 62.8
Naval Architecture and Marine Engineering	13	6	6	3	14	4	5	3	- 76.9
Nuclear Engineering	120	120	111	106	93	131	105	112	- 6.7
Ocean Engineering	1	9	10	36	28	12	13	20	+1,900.0
Petroleum Engineering	17	20	18	25	23	20	19	21	+ 23.5
Textile Engineering	1	3	0	3	1	0	1	1	0
Engineering, Other Fields	127	174	220	110	82	21	26	20	- 84.3
Total Engineering, United States	3,638	3,671	3,492	3,312	3,108	2,821	2,586	2,440	- 32.9
Computer and Information Sciences	128	167	196	198	213	244	216	196	+ 53.1
TOTAL	3,766	3,838	3,688	3,510	3,321	3,065	2,802	2,636	- 30.0%

Source: Department of Health, Education and Welfare; National Center for Education Statistics, Earned Degrees Conferred.

six fields of engineering plus computer and information sciences, a discipline closely interlocked with engineering. The sharp drop is tempered slightly by an advance in computer and information sciences. When these doctorate degree awards are added to the engineering totals, the overall decline is 30%, demonstrating the latent strength of the computer sciences field.

Table 2, page 11, summarizes the broadly based decline in doctoral degree production from academic year 1970-71 to 1977-78, reflecting a strong mood of apprehension among those who may be discouraged by the economic outlook. Eight fields gained, two fields stood still, and seventeen fields declined, the losses outnumbering the gains by more than a 2-to-1 ratio, a certain barometer of widely held views or broadly based circumstances, with the possibility there is a common denominator to explain the magnitude of opinion demonstrated by the lop-sided decline.

If one examines those fields that account for doctorate awards totaling one hundred or more, two fields exhibit gains, namely, Computer and Information Science, and Engineering, General; and ten fields exhibit losses, namely Nuclear Engineering, Industrial and Management Engineering, Chemical Engineering, Mechanical Engineering, Civil Engineering, Electrical Engineering, Aerospace Engineering, Engineering Mechanics, Metallurgical Engineering, and Engineering other fields. In this group, the declines outnumber the advances by a ratio of 5-to-1, reflecting high levels of interest in the advancing fields and strong uncertainties with the declining fields. It could also mean that those students who come to us in larger numbers are more often than not less prepared academically for the declining fields.

The bottom five casualties in this category are: Engineering, other fields (-84.3%); Metallurgical Engineering (-49.3%); Engineering Mechanics (-47.3%);

TABLE 2
U.S. ENGINEERING & COMPUTER AND INFORMATION SCIENCE DOCTORAL AWARDS
SUMMARY OF PERCENT CHANGES, BY MAGNITUDE OF CHANGE, 1971-1978

	Field of Engineering	N	N	Δ %
1.	Ocean Engineering	1	20	+1,900.0%
2.	Engineering Technologies	1	3	+ 200.0
3.	Bioengineering and Biomedical Engineering	29	61	+ 110.3
4.	Computer and Information Science	128	196	+ 53.1
5.	Materials Engineering	78	114	+ 46.2
6.	Engineering Physics	26	37	+ 42.3
7.	Petroleum Engineering	17	21	+ 23.5
8.	Engineering, General	219	235	+ 7.3
9.	Geophysical Engineering	1	1	0
10.	Textile Engineering	1	1	0
11.	Nuclear Engineering	120	112	- 6.7
12.	Industrial and Management Engineering	139	118	- 15.1
13.	Ceramic Engineering	25	19	- 24.0
14.	Environmental and Sanitary Engineering	49	36	- 26.5
15.	Agricultural Engineering	55	37	- 32.7
16.	Chemical Engineering	406	259	- 36.2
17.	Mechanical Engineering	438	279	- 36.3
18.	Civil Engineering	446	277	- 37.9
19.	Electrical Engineering	879	503	- 42.8
20.	Aerospace Engineering	217	115	- 47.0
21.	Engineering Mechanics	148	78	- 47.3
22.	Metallurgical Engineering	148	75	- 49.3
23.	Mining and Mineral Engineering	43	16	- 62.8
24.	Naval Architecture and Marine Engineering	13	3	- 76.9
25.	Engineering, other fields	127	20	- 84.3
26.	Architectural Engineering	3	0	- 100.0
27.	Geological Engineering	9	0	- 100.0
	TOTAL	3,766	2,636	- 30.0%

Aerospace Engineering (-47.0%); and Electrical Engineering (-42.8%). There is no relief in sight for Electrical Engineering. Doctoral productivity fell at an average annual compound rate of -11.13% from 1977 to 1978 compared with -7.66% over the seven-year span, indicating accelerating losses. (Please see Table 10, page 30 for related events.)

Other above average declines in this group are: Civil Engineering (-37.9%); Mechanical Engineering (-36.3%); and Chemical Engineering (-36.2%), fields less affected by catastrophic decline but squarely in the region of sharply tumbling numbers.

The number of engineering & computer science doctorates awarded from 1970 to 1978 are illustrated graphically in Figure 1, page 13. Following a 1.9% advance from 1971 to 1972, production figures fell sharply: -3.9% from 1972 to 1973; -4.8% from 1973 to 1974; -5.4% from 1974 to 1975; -7.7% from 1975-1976; -8.6% from 1976 to 1977; with the precipitous decline beginning to slow at -5.9% from 1977 to 1978, but still reflecting a strong mood of discouragement and possibly a strong awareness of the law of diminishing returns.

When computer and information science doctoral degree numbers are subtracted from the totals, comparable production figures are: a 0.9% rise from 1971 to 1972, and a steady tailspin as follows: -4.9% from 1972 to 1973; -5.2% from 1973 to 1974; -6.2% from 1974 to 1975; -9.2% from 1975 to 1976; -8.3% from 1976 to 1977; and -5.6% from 1977 to 1978.

Proportional changes in doctoral degree production are shown in Table 3, page 14. The numbers of degrees conferred in seventeen fields are studied for each of three two-year periods. (Ten of the specialty fields from the base data in Table 1 have been folded into other engineering to expedite evaluation.)

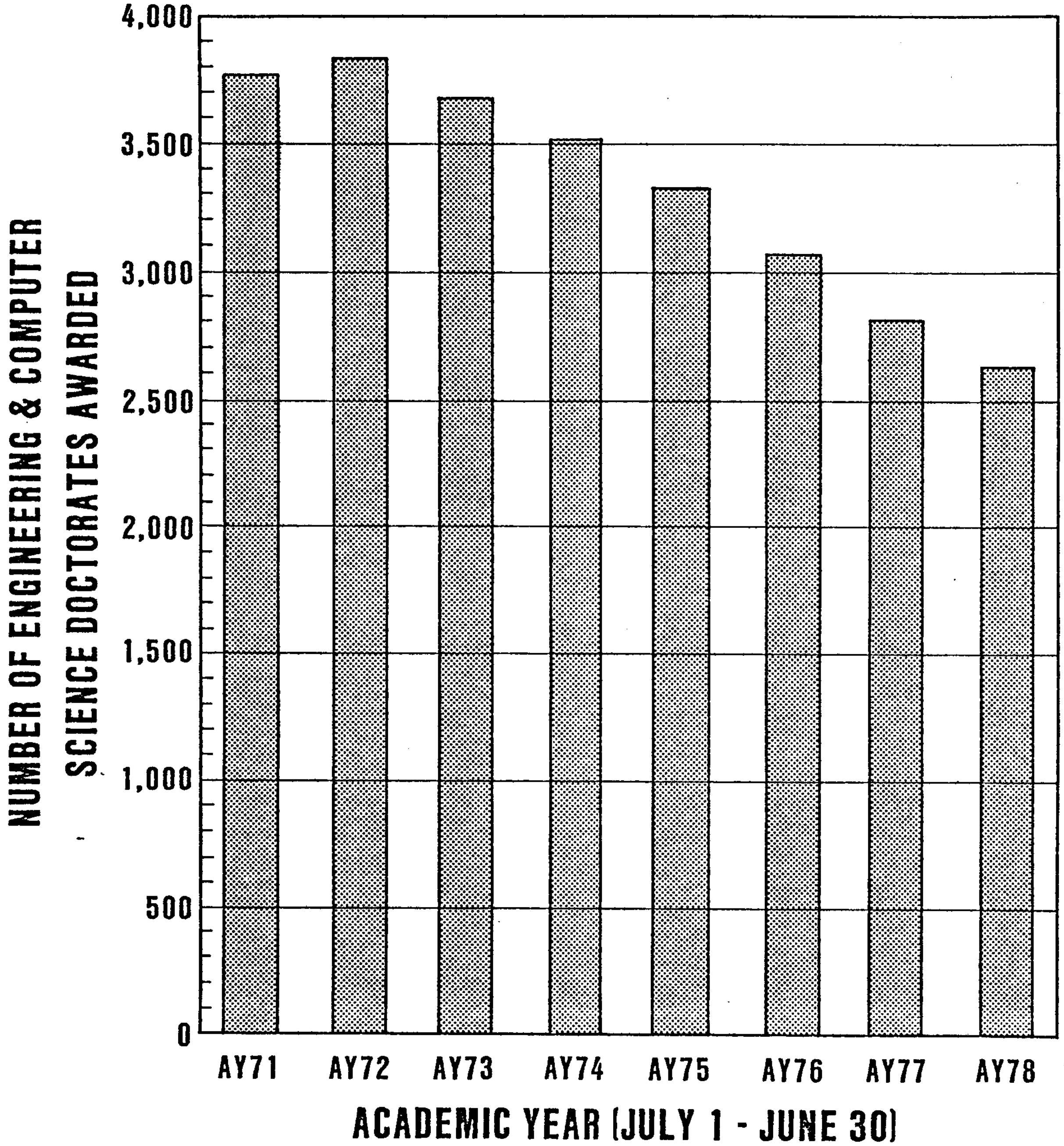

Figure 1: Engineering & Computer Science Doctorates Awarded in U.S.

TABLE 3
DOCTORATES AWARDED IN ENGINEERING & COMPUTER SCIENCE
NUMBER AND PERCENT FOR 1971&72, 1974&75, AND 1977&1978

Field Of Engineering	AY71 & 72		AY74 & 75		AY77 & 78		Ratio %T 74&75 / 71&72	Ratio %T 77&78 / 71&72
	N	%T	N	%T	N	%T		
Aerospace, Aeronautical, Astronautical Engineering	414	5.4	336	4.9	234	4.3	0.91	0.57
Agricultural Engineering	120	1.6	97	1.4	58	1.1	0.88	0.69
Bioengineering and Biomedical Engineering	75	1.0	98	1.4	108	2.0	1.40	2.00
Chemical Engineering	800	10.5	746	10.9	550	10.1	1.04	0.96
Civil, Construction, and Transportation Engineering	861	11.3	724	10.6	586	10.8	0.94	0.96
Electrical, Electronics, Communication Engineering	1,703	22.4	1,406	20.6	1,069	19.7	0.92	0.88
Engineering, General	503	6.6	547	8.0	518	9.5	1.21	1.44
Engineering Mechanics	295	3.9	280	4.1	159	2.9	1.05	0.74
Engineering Physics	56	0.7	46	0.7	75	1.4	0.82	2.00
Environmental and Sanitary Engineering	90	1.2	114	1.7	88	1.6	1.42	1.33
Industrial and Management Engineering	307	4.0	265	3.9	222	4.1	0.98	1.03
Materials Engineering	174	2.3	191	2.8	247	4.5	1.22	1.96
Mechanical Engineering	849	11.2	725	10.6	562	10.3	0.95	0.92
Metallurgical Engineering	275	3.6	218	3.2	129	2.4	0.89	0.67
Nuclear Engineering	240	3.2	199	2.9	217	4.0	0.91	1.25
Engineering Other Fields	547	7.2	428	6.3	204	3.8	0.88	0.53
Computer and Information Sciences	295	3.9	411	6.0	412	7.6	1.54	1.95
Total Engineering + Computer Science	7,604	100.0	6,831	100.0	5,438	100.1	1.00	1.00

Relative changes in the pattern of doctoral degree production are measured by dividing the percentages in 1974&75, and in 1977&78 by the percentages in 1971&1972. This produces ratios, shown in the last two columns of Table 3, that gauge differences in rates and magnitude of change from field to field.

To facilitate understanding of the size and scope of this movement, the rates of change for the seventeen fields are rank ordered in Table 4, page 16 according to the magnitude of variation in 1977&78 over 1971&72. Ratios greater than 1.00 exhibit above average progression, and ratios less than 1.00 exhibit below average progression.

Bioengineering and Biomedical Engineering, Engineering Physics, and Materials Engineering are the three fields showing the greatest relative advance, indicating optimistic expectations about future growth.

Other engineering (relatively small specialty fields), Aerospace Engineering, and Metallurgical Engineering are the three fields showing the greatest slump, which may reflect pessimistic expectations on economic futures, lingering fears about the instability of hard hit industries and academic concerns about mature fields.

The rankings in Table 4 also aid in the recognition of trends. For example, Bioengineering and Biomedical Engineering show consistent improvement over both periods, rising increasingly in rank. Engineering Physics displayed the weakest performance at mid-period, but made a strong recovery to show a 100% gain in its proportion of doctoral degree production from the 1971&72 period to the 1977&78 period. Materials Engineering demonstrates consistent advance in the fraction of degrees conferred. Computer and information science held first rank at the 1974&75 midpoint, but lost ground at the end of the period,

TABLE 4

RANKINGS OF DOCTORATES AWARDED FOR 1977&1978/1971&1972
AND FOR 1974&75/1971&72, BY MAGNITUDE OF CHANGE IN PERCENT OF TOTAL

Rank 74&75 / 71&72	Rank 77&78 / 71&72	Field Of Engineering	Ratio 74&75 / 71&72	Ratio 77&78 / 71&72
3	1	Bioengineering and Biomedical Engineering	1.40	2.00
15	1	Engineering Physics	0.82	2.00
4	2	Materials Engineering	1.22	1.96
1	3	Computer and Information Science	1.54	1.95
5	4	Engineering, General	1.21	1.44
2	5	Environmental and Sanitary Engineering	1.42	1.33
12	6	Nuclear Engineering	0.91	1.25
8	7	Industrial and Management Engineering	0.98	1.03
7	8	Chemical Engineering	1.04	0.96
10	8	Civil, Construction, and Transportation Engineering	0.94	0.96
9	9	Mechanical Engineering	0.95	0.92
11	10	Electrical, Electronics, Communication Engineering	0.92	0.88
6	11	Engineering Mechanics	1.05	0.74
14	12	Agricultural Engineering	0.88	0.69
13	13	Metallurgical Engineering	0.89	0.67
12	14	Aerospace, Aeronautical, Astronautical Enginering	0.91	0.57
14	15	Other Engineering	0.88	0.53

a reflection of stabilization that occurred in the last half of the period. It is doubtful that this indicates weakening interest as much as a tightening student pool.

Of those fields displaying below average progress, the specialty fields show a constant loss of ground, falling from fourteenth to fifteenth rank by the end of the period. Aerospace, Aeronautical and Astronautical Engineering posted one decline after the other, finishing fourteenth of fifteen, as the arithmetic of undergraduate degree production intruded itself into the equation of graduate production.

Taken together, these data portray doctoral degree production decelerating rapidly, with a shifting and mounting emphasis away from the bedrock fields. This would lead one to believe that the converging forces of faculty attrition and sharply falling Ph.D. production will create an overwhelming combination of strategic, economic, and educational forces that will pose serious challenges to the nation's engineering schools. This belief is buttressed by the knowledge (Chesson[6]) that even in the best of times (the late nineteen sixties) only some 45% of engineering doctorate recipients accept academic employment. Against the background of aging facilities, lackluster salaries, and faltering external support, the range of responses are severely limited, making it extremely difficult to compete. Coupled with shifting demographics that will result in a __% decline in undergraduate enrollments over the next decade, the scenario is reminiscent of the curtain call for a great American tragedy.

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6 Ibid, p. 738.

RELATIVE ATTRITION IN ENGINEERING DOCTORAL STUDY:

SHARPLY FALLING RATIOS OF DOCTORATES TO BACCALAUREATES

Aggravating the falling doctorate degree production is a steady decline in the ratio of doctorates awarded to baccalaureates. Whereas baccalaureate degree production advanced on the average at a modest compound annual rate of 1.53% from 1971 to 1978, doctorate degree production suffered because an ever declining proportion of engineering students have pursued doctoral study. To illustrate, there follows a comparison of the ratio of doctoral awards to baccalaureates awards earned four years earlier, which validates the erosion.

Table 5

Comparison of Engineering Doctorate Awards With

Baccalaureate Awards; Declining Ratios

5a, Engineering, United States

1		2		3	4
				Ratio	Ratio
Doctorates		Baccalaureates		Doc:Bac	Bac:Doc
AY	N	AY	N	1/2	2/1
1975	3,108	1971	50,046	0.062:1	16.102:1
1976	2,821	1972	51,164	0.055:1	18.137:1
1977	2,586	1973	51,265	0.050:1	19.824:1
1978	2,440	1974	50,286	0.049:1	20.609:1

5b, Engineering & Computer and Information Science

1		2		3	4
				Ratio	Ratio
Doctorates		Baccalaureates		Doc:Bac	Bac:Doc
AY	N	AY	N	1/2	2/1
1975	3,321	1971	52,434	0.063:1	15.789:1
1976	3,065	1972	54,566	0.056:1	17.803:1
1977	2,802	1973	55,569	0.050:1	19.832:1
1978	2,636	1974	55,042	0.048:1	20.881:1

The data in Table 5a tell us that from 1975 to 1978, the ratio of doctorates to baccalaureates four years earlier fell steadily, declining to 4.9% of the pool from 6.2% of the pool, or 21%. This means there were 20.6 baccalaureates in 1974 to each doctorate in 1978, compared with only 16.1 baccalaureates in 1971 to each doctorate in 1975, or 28% more.

Table 5b includes computer and information sciences in the totals. This tells us that from 1975 to 1978, the ratio of doctorates to baccalaureates four years earlier also fell steadily, declining to 4.8% of the pool from 6.3% of the pool, or 24%. This means there were 20.9 baccalaureates in 1974 to each doctorate in 1978, compared with 15.8 baccalaureates in 1971 to each doctorate in 1975, or 32% more.

This confirms that the problem of graduate degree productivity runs deeper than school age population demographics, albeit an important contributing element. And it can not be attributed to the foreign national composition of the Ph.D. population; it is well known that this component has remained constant. When baccalaureate degree production is rising, even slightly, and doctorate production is falling dramatically, it leads one to the inescapable conclusion, buttressed by what Table 5 tells us, that we are pumping an increasingly dry well.

Primarily, it would seem to reflect a steadily declining pool of qualified students with interest in advanced scientific subjects, possibly reinforced by declining expectations as to the value of attaining advanced academic credentials. We have seen evidence of deterioration in the value of advanced engineering degrees resulting from market influences that would tend to validate these assumptions. If true, it would suggest that we must today encourage solutions to these issues to ensure the future of American engineering and science.

That action is needed to strengthen the competitive position of U.S. engineering is underscored by the implications for a decline in doctorate-to-baccalaureate ratios to a point today that is the worst in twenty years. The ratio of doctorates to baccalaureates four years earlier rose steadily over the sixteen year period from 1954 to 1970, climbing to a level of .1034 from .0114 (10-in-100 from 1-in-100), as shown in Table 5c, page 21. Thereafter, the ratio declined in a straight line, falling to 0.0485 (approximately 5-in-100) by 1977-78. Because the relationship between passing time and declining ratios are closely correlated (r=0.98) over the eight year span, it is possible to predict what will happen in the future if the deterioration goes unchecked. Three sets of estimates were drawn up (please see Table 5d, page 22) using the "optimistic" assumptions of the 8-year span; the pessimistic assumption based on the more sharply falling line attributable to the 4-year span from 1973-74 to 1977-78, and a mid-point estimate that represents the average of these two.

TABLE 5c
COMPARISON OF ENGINEERING DOCTORATE AWARDS
WITH BACCALAUREATE AWARDS FOUR YEARS EARLIER
1953-54 TO 1977-78 WITH PROJECTION TO 1981-82

(1) X Doctorates		(2) Y Baccalaureates		(3) Ratio X/Y	(4) Ratio Y/X
AY	N	AY	N	Doc:Bac	Bac:Doc
1953-54	594	1949-50	52,246	0.0114	87.9562
1955-56	610	1952-52	30,492	0.0200	49.9869
1957-58	647	1953-54	22,227	0.0291	34.3539
1959-60	786	1955-56	26,219	0.0300	33.3575
1961-62	1,207	1957-58	35,191	0.0343	29.1558
1963-64	1,693	1959-60	37,679	0.0449	22.2558
1965-66	2,304	1961-62	34,551	0.0667	14.9961
1967-68	2,932	1963-64	38,013	0.0771	12.9649
1969-70	3,681	1965-66	35,615	0.1034	9.6754
1970-71	3,638	1966-67	N/A	N/A	N/A
1971-72	3,671	1967-68	37,368	0.0982	10.1792
1972-73	3,492	1968-69	N/A	N/A	N/A
1973-74	3,108	1970-71	50,046	0.0621	16.1023
1975-76	2,821	1971-72	51,164	0.0551	18.1368
1976-77	2,586	1972-73	51,265	0.0504	19.8241
1977-78	2,440	1973-74	50,286	0.0485	20.6090
1978-79	2,060	1974-75	46,852	0.044	22.629
1979-80	1,900	1975-76	46,331	0.041	24.314
1980-81	1,870	1976-77	49,283	0.038	25.998
1981-82	2,000	1977-78	55,654	0.036	27.682

TABLE 5d
LINEAR ESTIMATES OF DOCTORAL DEGREE AWARDS
ACADEMIC YEAR 1978-79 to 1981-82

Optimistic Estimate			
AY 79	22.213	0.045	2,110
AY 80	23.774	0.042	1,900
AY 81	25.334	0.039	1,870
AY 82	26.895	0.037	2,060

Mid Point Estimate			
AY 79	22.629	0.044	2,060
AY 80	24.314	0.041	1,900
AY 81	25.998	0.038	1,870
AY 82	27.682	0.036	2,000

Pessimistic Estimate			
AY 79	23.045	0.043	2,010
AY 80	24.853	0.040	1,850
AY 81	26.661	0.038	1,870
AY 82	28.469	0.035	1,950

Induced doctorate degree estimates for the period from 1978 to 1982 are derived by the application of the projected ratios to the 1974-75 to 1977-78 baccaalaureate degree awards. These show doctorate productivity falling from 2,440 in 1977-78 to 2,000 in 1981-82, or at an average annual compound rate of -4.85%. While this number represents an improvement over the -5.55% average annual compound rate at which production fell from 1971 to 1978, it may create considerable disquiet in the hearts and minds of U.S. engineering schools.

Decaying steadily over an eight year period, this index is an important indicator of future doctoral productivity strength. The long term consecutive annual decline is an apparent indication that Ph.D. productivity will remain severely depressed for some time. The tumbling index implies that activity will remain sluggish until the curve bottoms out and shows signs of a turnaround. It is hard to gauge how far it will fall for there is no precedent for a decline of this magnitude in the data going back 30 years. There is a sign of some slowing in the rate of deterioration, but certainly no evidence of stabilization and not a single hint that sustained advance is yet in sight.

We are of the opinion that the question as to the changes that had become manifest in the last half of the nineteen seventies will resolve itself by establishing the attitudes, early training, available numbers, and economic circumstances of the 1971-74 student cohort; the evolution of the engineering fields that was taking place during those years; developments that occurred within and among the various fields at that time; and the economic forces at work in this environment. Identical data for the last half of the nineteen seventies would tell us more about likely developments in the first half of the nineteen eighties.

MORE SIGNS OF PRODUCTIVITY STRAINS: EVOLUTIONARY DRIFT

By incorporating knowledge of baccalaureate degree activity into our analysis, our investigation of doctoral productivity was enhanced. Further signs of potential productivity strains reveal themselves in engineering baccalaureate degree statistics.

Although engineering baccalaureate degrees conferred rose 11.2% from 1971 to 1978, the advance was substantially uneven. Computer and information science was a strong leader and when these awards are added to the totals, an overall gain of 19.9% was posted. Table 6, page 25 details the baccalaureates awarded by engineering field academic year-by-year from 1971 to 1978 and shows the percent change in the numbers over the total period. A summary of the advance is displayed in Table 7, page 27 in order of magnitude.

Eighteeen fields advanced with percent gains ranging from 0.2% to 472.2%. The top two leaders were Environmental and Sanitary Engineering and Bioengineering and Biomedical Engineering. Nine fields declined with percent losses ranging from -8.7% to -71.7%. The two greatest casualties were Textile Engineering, and Engineering, other fields. Hence, advances outnumbered declines by a ratio of 2-to-1, a healthy indication of broad interest in a majority of the engineering baccalaureate programs and the power of the undergraduate degree.

Among the major fields, Aerospace Engineering posted the highest decline, falling 51.5%. Metallurgical Engineering declined 32.6%, Industrial and Management Engineering fell 15.5%, and Electrical Engineering was down 8.7%, as students shunned aerospace engineering and metals engineering and as the others followed the economy down.

TABLE 6
BACCALAUREATES AWARDED IN ENGINEERING FIELDS AND IN COMPUTER AND INFORMATION SCIENCE -- UNITED STATES

Field Of Engineering	Academic Year (July 1-June 30) AY 71	AY 72	AY 73	AY 74	AY 75	AY 76	AY 77	AY 78	Δ % AY 71-AY 78
Aerospace, Aeronautical, Astronautical Engineering	2,443	2,180	1,738	1,210	1,174	1,009	1,078	1,186	- 51.5
Agricultural Engineering	504	447	493	522	417	412	500	551	9.3
Architectural Engineering	272	253	324	306	283	221	277	326	19.9
Bioengineering and Biomedical Engineering	68	65	86	152	151	193	253	350	414.7
Ceramic Engineering	178	196	202	191	143	147	144	152	- 14.6
Chemical Engineering	3,579	3,625	3,578	3,399	3,070	3,140	3,524	4,569	27.7
Civil Construction and Transportation Engineering	6,526	6,803	7,390	8,017	7,651	7,923	8,228	9,135	40.0
Electrical, Electronics, Communications Engineering	12,198	12,101	12,313	11,316	10,161	9,791	9,936	11,133	- 8.7
Engineering, General	2,864	2,925	2,628	3,087	2,893	3,168	3,348	3,328	16.2
Engineering Mechanics	260	210	211	146	140	143	156	176	- 32.3
Engineering Physics	373	469	277	281	261	335	213	236	- 36.7
Engineering Technologies	5,148	5,772	4,854	7,446	7,464	7,943	8,347	8,785	70.6
Environmental and Sanitary Engineering	54	96	187	182	216	213	245	309	472.2
Geological Engineering	123	111	123	127	115	112	132	157	27.6
Geophysical Engineering	26	65	24	37	33	52	49	56	115.4
Industrial and Management Engineering	3,171	3,680	3,458	2,870	2,522	2,203	2,240	2,678	- 15.5
Materials Engineering	76	116	105	161	157	190	216	234	207.9
Mechanical Engineering	8,858	8,530	8,523	7,677	6,890	6,800	7,703	8,875	0.2
Metallurgical Engineering	623	579	558	458	393	351	350	420	- 32.6
Mining and Mineral Engineering	158	169	201	279	308	331	404	509	222.2
Naval Architecture and Marine Engineering	416	304	288	379	419	402	430	567	36.3
Nuclear Engineering	250	312	328	309	361	418	480	545	118.0
Ocean Engineering	64	164	88	136	210	157	132	162	153.1
Petroleum Engineering	292	304	332	372	278	340	405	590	102.1
Textile Engineering	212	65	34	52	29	20	45	60	- 71.7
Engineering, Other Fields	1,310	1,623	2,922	1,174	1,113	317	448	565	- 56.9
Total Engineering, United States	50,046	51,164	51,265	51,286	46,852	46,331	49,283	55,645	11.2
Computer and Information Sciences	2,388	3,402	4,304	4,756	5,033	5,652	6,407	7,201	201.5
TOTAL	52,434	54,566	55,569	55,042	51,885	51,983	55,690	62,855	19.9

Source: Department of Health, Education and Welfare; National Center for Education Statistics, Earned Degrees Conferred.

TABLE 7

U.S. ENGINEERING & COMPUTER AND INFORMATION SCIENCE BACCALAUREATE AWARDS

SUMMARY OF PERCENT CHANGES, BY MAGNITUDE OF CHANGE, 1971-1978

	Field of Engineering	N	N	Δ %
1.	Environmental & Sanitary Engineering	54	309	472.2%
2.	Bioengineering and Biomedical Engineering	68	350	414.7
3.	Mining and Mineral Engineering	158	509	222.2
4.	Materials Engineering	76	234	207.9
5.	Computer and Information Sciences	2,388	7,201	201.5
6.	Ocean Engineering	64	162	153.1
7.	Nuclear Engineering	250	545	118.0
8.	Geophysical Engineering	26	56	115.4
9.	Petroleum Engineering	292	590	102.1
10.	Engineering Technologies	5,148	8,785	70.6
11.	Civil, Construction, and Transportation Engineering	6,526	9,135	40.0
12.	Naval Architecture	416	567	36.3
13.	Chemical Engineering	3,579	4,569	27.7
14.	Geological Engineering	123	157	27.6
15.	Architectural Engineering	272	326	19.9
16.	Engineering, General	2,864	3,328	16.2
17.	Agricultural Engineering	504	551	9.3
18.	Mechanical Engineering	8,858	8,875	0.2
19.	Electrical, Electronics, and Communication Engineering	12,198	11,133	- 8.7
20.	Ceramic Engineering	178	152	-14.6
21.	Industrial and Management Engineering	3,171	2,678	-15.5
22.	Engineering Mechanics	260	176	-32.3
23.	Metallurgical Engineering	623	420	-32.6
24.	Engineering Physics	373	236	-36.7
25.	Aerospace, Aeronautical, and Astronautical Engineering	2,443	1,186	-51.5
26.	Engineering, other fields	1,310	565	-56.9
27.	Textile Engineering	212	60	-71.7
	TOTAL	52,434	62,855	19.9%

Relative growth is displayed in Table 8, page 28 using the methodology introduced earlier (in Table 3). This describes degree production for seventeen areas of engineering & computer sciences over three two-year periods and takes a look at proportional rates of advance. These changes are summarized and ranked in order of magnitude in Table 9, page 29.

Bioengineering and Biomedical Engineering, Mining and Mineral Engineering, and Computer and Information Sciences strongly lead the advance with brisk and consistent gains that boosted their positions more than twice over that held seven years earlier. There were no signs of slowdown in the fast pace for Bioengineering, and for Mining, indicating a sustained future upswing. Sustained advance at a lessening pace is evident in the computer science climb.

Aerospace Engineering, Metallurgical Engineering, and the Engineering specialty fields trail the group at a substantially lagging distance.

Other casualties with below average advancement are Industral and Management Engineering, Electrical Engineering, and Mechanical Engineering, implying continuing sluggish activity.

Characterized by broad field variations in the pattern of growth, these evolutionary changes will test the resourcefulness of engineering deans to redeploy resources to maintain degree productivity across a ragged front; to encourage developments in the advancing fields and to avert disaster in those areas increasingly faced with academic extinction. Difficult challenges will be faced in areas such as Electrical Engineering where the ratio of doctorates to baccalaureates four years earlier is deteriorating more rapidly than engineering as a whole and is starting from a generally weaker productivity margin. Table 10 illustrates

TABLE 8
BACCALAUREATES AWARDED IN ENGINEERING & COMPUTER SCIENCE
NUMBER AND PERCENT FOR 1971 & 72, 1974 & 75, and 1977 & 78

Field Of Engineering	Academic Year (July 1-June 30)						Ratio	Ratio
	AY71 & AY72		AY74 & AY 75		AY77 & AY78		%74&75	%77&78
	N	%T	N	%T	N	%T	71&72	71&72
Aerospace, Aeronautical, Astronautical Engineering	4,623	4.32	2,384	2.23	2,264	1.91	0.52	0.44
Agricultural Engineering	951	0.89	939	0.88	1,051	0.89	0.99	1.00
Architectural Engineering	525	0.49	589	0.55	603	0.51	1.12	1.04
Bioengineering and Biomedical Engineering	133	0.12	303	0.28	603	0.51	2.33	4.25
Chemical Engineering	7,204	6.73	6,469	6.05	8,093	6.83	0.90	1.01
Civil, Construction, and Transportation Engineering	13,329	12.46	15,668	14.65	17,363	14.65	1.18	1.18
Electrical, Electronics, Communications Engineering	24,299	22.71	21,477	20.09	21,069	17.77	0.88	0.78
Engineering, General	5,789	5.41	5,980	5.59	6,676	5.63	1.03	1.04
Engineering Technologies	10,920	10.21	14,910	13.94	17,132	14.45	1.37	1.42
Industrial and Management Engineering	6,851	6.40	5,392	5.04	4,918	4.15	0.79	0.65
Mechanical Engineering	17,388	16.25	14,567	13.62	16,578	13.98	0.84	0.86
Metallurgical Engineering	1,202	1.12	851	0.80	770	0.65	0.71	0.85
Mining and Mineral Engineering	327	0.31	587	0.55	913	0.77	1.77	2.48
Naval Architecture and Marine Engineering	720	0.67	798	0.75	997	0.84	1.12	1.25
Nuclear Engineering	562	0.53	670	0.63	1,025	0.86	1.19	1.62
Petroleum Engineering	596	0.56	650	0.61	995	0.84	1.09	1.50
Engineering, Other Fields	5,791	5.41	4,904	4.59	3,887	3.28	0.85	0.61
Computer and Information Sciences	5,790	5.41	9,789	9.15	13,608	11.48	1.69	2.12
TOTAL	107,000	100.00	106,927	100.00	118,545	100.00	1.00	1.00

TABLE 9
RANKINGS OF BACCALAUREATES AWARDED FOR 1977 & 78/1971 & 72
AND FOR 1974 & 75/1971 & 72, BY MAGNITUDE OF CHANGE IN PERCENT OF TOTAL

Rank 74&75 / 71&72	Rank 77&78 / 71&72	Field Of Engineering	Ratio 74&75 / 71&72	Ratio 77&78 / 71&72
1	1	Bioengineering and Biomedical Engineering	2.33	4.25
2	2	Mining and Mineral Engineering	1.77	2.48
3	3	Computer and Information Science	1.69	2.12
5	4	Nuclear Engineering	1.19	1.62
8	5	Petroleum Engineering	1.09	1.50
4	6	Engineering Technologies	1.37	1.42
7	7	Naval Architecture and Marine Engineering	1.12	1.25
6	8	Civil, Construction, and Transportation Engineering	1.18	1.18
7	9	Architectural Engineering	1.12	1.04
9	9	Engineering, General	1.03	1.04
10	10	Chemical Engineering	0.90	1.01
10	11	Agricultural Engineering	0.90	1.00
13	12	Mechanical Engineering	0.84	0.86
11	13	Electrical, Electronics, Communication Engineering	0.88	0.78
14	14	Industrial and Management Engineering	0.79	0.65
12	15	Engineering, Other Fields	0.85	0.61
15	16	Metallurgical Engineering	0.71	0.58
16	17	Aerospace, Aeronautical, Astronautical Enginering	0.52	0.44

Table 10

Comparison of Engineering Doctorate Awards with

Baccalaureate Awards; Declining Ratios

Electrical Engineering, Electronics, Communications Engineering

1		2		3	4
				Ratio	Ratio
Doctorates		Baccalaureates		Doc:Bac	Bac:Doc
AY	N	AY	N	1/2	2/1
1975	701	1971	12,198	0.057:1	17.401:1
1976	649	1972	12,101	0.054:1	18.646:1
1977	566	1973	12,313	0.046:1	21.754:1
1978	503	1974	11,316	0.044:1	22.497:1

This comparison shows that the ratio of doctorates to baccalaureates deteriorated throughout the period, declining to 4.4% of the pool from 5.7% of the pool, or 23%. This means that an increasingly larger pool of baccalaureates was required to produce the 1978 doctoral degree compared with the 1975 doctoral degrees, an increase to 22.5 from 17.4, or 29% more. As one can see, the baccalaureate pool declined to 11,316 from 12,198 from 1971 to 1974, -7.2%, creating a deadly combination of unfavorable circumstances, the classical double whammy. As a result, EE's doctoral field is hemorrhaging.

LAGGING MASTER'S DEGREES

Although some engineering fields posted impressive gains in master's productivity from 1971 to 1978 (notably Bioengineering and Biomedical Engineering, and Environmental and Sanitary Engineering), U.S. Engineering M.S. productivity fell by -0.3%, to 16,398 degree awards from 16,443 awards seven years earlier. The totals were dragged down primarily by faltering degree production in a number of large areas, namely, the specialty fields (-82%), Aerospace Engineering (-42.7%), Mechanical Engineering (-13.2%) and Industrial and Management Engineering (-10.4%).

The advance othewise was broadly based with advances outnumbering declines by a ratio of 1.7-to-1. Table 11, page 32, details the highly mixed activity academic year-by-year from 1971 to 1978.

Table 12, page 33, summarizes the gains and losses over the seven year period, indicating that the gains ranged from 5.6% to 171.4%, while the losses ranged from -2.0% to -82%.

For those fields representing at least one percent of the awards in 1978, we find that the three top leaders are Engineering Technologies; Bioengineering and Biomedical Engineering; and Environmental and Sanitary Engineering with strong performances hinting at sustained future advance.

In the same "1%-of-the-awards" category, we find Aerospace Engineering, Metallurgical Engineering; and Mechanical Engineering lagging at the bottom, reflecting substantially recessionary tendencies.

Lagging near the bottom are Electrical Engineering, and Industrial Engineering. From 1977-78, EE's slide slowed to a compound rate of -1.3% a year compared with a -1.9% decline from 1971-78, evidence of slight deceleration in the decline but hinting that activity will remain sluggish. Industrial Engineering tumbled at a compound rate of 1.55% from 1971 to 1978, but demonstrates 7% growth from AY 77 to 78, an indication that activity has stabilized and might pick up momentum.

TABLE 11
MASTERATES AWARDED IN ENGINEERING FIELDS AND IN
COMPUTER AND INFORMATION SCIENCE -- UNITED STATES

Field Of Engineering	Academic Year (July 1-June 30) AY 71	AY 72	AY 73	AY 74	AY 75	AY 76	AY 77	AY 78	Δ % AY 71-AY 78
Aerospace, Aeronautical, Astronautical Engineering	717	687	563	557	477	479	385	411	- 42.7%
Agricultural Engineering	135	177	171	151	135	146	147	144	6.7
Architectural Engineering	31	23	39	24	30	37	20	18	- 41.9
Bioengineering and Biomedical Engineering	73	88	114	142	161	178	175	191	161.6
Ceramic Engineering	39	60	53	68	49	52	57	47	20.5
Chemical Engineering	1,100	1,154	1,051	1,044	990	1,031	1,086	1,235	12.3
Civil Construction and Transportation Engineering	2,425	2,487	2,627	2,652	2,769	2,999	2,964	2,685	10.7
Electrical, Electronics, Communications Engineering	4,282	4,206	3,895	3,499	3,469	3,774	3,788	3,740	- 12.7
Engineering, General	813	991	817	907	1,149	1,305	1,435	1,593	95.9
Engineering Mechanics	264	269	254	214	172	181	141	152	- 42.4
Engineering Physics	65	78	57	116	43	85	94	106	63.1
Engineering Technologies	134	237	122	209	221	328	284	360	168.7
Environmental and Sanitary Engineering	238	359	527	570	467	568	617	517	117.2
Geological Engineering	39	40	41	34	44	28	44	52	33.3
Geophysical Engineering	7	7	6	13	19	3	14	19	171.4
Industrial and Management Engineering	1,921	1,731	1,595	1,734	1,687	1,751	1,609	1,722	- 10.4
Materials Engineering	124	165	215	208	198	223	237	224	80.6
Mechanical Engineering	2,237	2,282	2,141	1,843	1,858	1,907	1,952	1,942	- 13.2
Metallurgical Engineering	273	264	279	216	224	176	165	204	- 25.3
Mining and Mineral Engineering	66	76	53	64	59	70	77	92	39.4
Naval Architecture and Marine Engineering	71	51	72	55	69	102	87	75	5.6
Nuclear Engineering	329	383	399	400	424	466	485	494	50.2
Ocean Engineering	52	77	112	80	99	118	105	110	111.5
Petroleum Engineering	100	105	88	66	88	98	93	98	- 2.0
Textile Engineering	32	21	18	22	14	13	12	9	- 71.9
Engineering, Other Fields	876	942	1,310	491	433	224	172	158	- 82.0
Total Engineering, United States	16,443	16,960	16,619	15,379	15,348	16,342	16,245	16,398	- 0.3
Computer and Information Sciences	1,588	1,977	2,113	2,276	2,299	2,603	2,798	3,038	91.3
TOTAL	18,031	18,937	18,732	17,655	17,647	18,945	19,043	19,436	7.8%

Source: Department of Health, Education and Welfare; National Center for Education Statistics, Earned Degrees Conferred.

TABLE 12

U.S. ENGINEERING & COMPUTER AND INFORMATION SCIENCE MASTERATE AWARDS

SUMMARY OF PERCENT CHANGES, BY MAGNITUDE OF CHANGE, 1971-1978

	Field of Engineering	AY 71 N	AY 78 N	Δ %
1.	Geophysical Engineering	7	19	171.4%
2.	Engineering Technologies	134	360	168.7
3.	Bioengineering and Biomedical Engineering	73	191	161.6
4.	Environmental and Sanitary Engineering	238	517	117.2
5.	Ocean Engineering	52	110	111.5
6.	Engineering, General	813	1,593	95.9
7.	Computer and Information Sciences	1,588	3,038	91.3
8.	Materials Engineering	124	224	80.6
9.	Engineering Physics	65	106	63.1
10.	Nuclear Engineering	329	494	50.2
11.	Mining and Mineral Engineering	66	92	39.4
12.	Geological Engineering	39	52	33.3
13.	Ceramic Engineering	39	47	20.5
14.	Chemical Engineering	1,100	1,235	12.3
15.	Civil, Construction, and Transportation Engineering	2,425	2,685	10.7
16.	Agricultural Engineering	135	144	6.7
17.	Naval Architecture and Marine Engineering	71	75	5.6
18.	Petroleum Engineering	100	98	- 2.0
19.	Industrial and Management Engineering	1,921	1,722	-10.4
20.	Electrical, Electronics, and Communications Engineering	4,282	3,740	-12.7
21.	Mechanical Engineering	2,237	1,942	-13.2
22.	Metallurgical Engineering	273	204	-25.3
23.	Architectural Engineering	31	18	-41.9
24.	Engineering Mechanics	264	152	-42.4
25.	Aerospace, Aeronautical, and Astronautical Engineering	717	411	-42.7
26.	Textile Engineering	32	9	-71.9
27.	Engineering, Other Fields	876	158	-82.0
	TOTAL	18,031	19,436	7.8%

Table 13, page 35 takes a close look at the number and percent of master's degrees awarded for three two-year periods (1971&72, 1974&1975, and 1977&1978) and measures relative movement over these periods.

Rankings are given in Table 14, page 36 by magnitude of advance in 1977&78 over 1971&72. With an advance ratio of over 2-to-1, Bioengineering and Biomedical Engineering is in a rank by itself. Environmental Engineering and Engineering Technologies, with ratios of 1.8-to-1 and 1.7-to-1, respectively, show strong growth capabilities.

Showing the strongest decline are the engineering specialty fields, in a category of their own at the bottom (moving at 4-tenths the average pace); Engineering Mechanics (5-tenths the average pace); and Aerospace Engineering (also 5-tenths the average pace).

Decline in the specialty fields shows no evidence of bottoming out, although the fall in 1977-78 was less sharp, -8.0%, compared with the annual compound rate of fall from 1971 to 1978, -21.7%. Engineering Mechanics stopped falling by 1977 and rose slightly in 1978. Aerospace Engineering also bottomed out in 1977 and started upwards, an indication that the worst perhaps is part of the past.

TABLE 13

MASTERATES AWARDED IN ENGINEERING & COMPUTER SCIENCE

NUMBER AND PERCENT FOR 1971 & 72, 1974 & 75, and 1977 & 78

Field Of Engineering	Academic Year (July 1-June 30) AY71 & AY72 N	AY71 & AY72 %T	AY74 & AY 75 N	AY74 & AY 75 %T	AY77 & AY78 N	AY77 & AY78 %T	Ratio %74&75 / 71&72	Ratio %77&78 / 71&72
Aerospace, Aeronautical, Astronautical Engineering	1,404	3.80	1,034	2.93	796	2.07	0.77	0.54
Agricultural Engineering	312	0.84	286	0.81	291	0.76	0.96	0.01
Bioengineering and Biomedical Engineering	161	0.44	303	0.86	366	0.95	1.95	2.16
Chemical Engineering	2,254	6.10	2,034	5.76	2,321	6.03	0.94	0.99
Civil, Construction, and Transportation Engineering	4,912	13.29	5,421	15.36	5,649	14.68	1.16	1.10
Electrical, Electronics, Communications Engineering	8,488	22.96	6,968	19.74	7,528	19.56	0.86	0.85
Engineering, General	1,804	4.88	2,056	5.82	3,028	7.87	1.19	1.61
Engineering Mechanics	533	1.44	386	1.09	293	0.76	0.76	0.53
Engineering Physics	143	0.39	159	0.45	200	1.52	1.15	1.33
Engineering Technologies	371	1.00	430	1.22	644	1.67	1.22	1.67
Environmental and Sanitary Engineering	597	1.61	1,037	2.94	1,134	2.95	1.83	1.83
Industrial and Management Engineering	3,652	9.88	3,421	9.69	3,331	8.66	0.98	0.88
Materials Engineering	289	0.78	406	1.15	461	1.20	1.47	1.54
Mechanical Engineering	4,519	12.22	3,701	10.48	3,894	10.12	0.86	0.83
Metallurgical Engineering	537	1.45	440	1.25	369	0.96	0.86	0.66
Nuclear Engineering	712	1.93	824	2.33	979	2.54	1.21	1.32
Ocean Engineering	129	0.35	179	0.51	215	0.56	1.46	1.60
Petroleum Engineering	205	0.55	154	0.44	191	0.50	0.80	0.91
Engineering, Other Fields	2,381	6.44	1,488	4.22	953	2.48	0.66	0.39
Computer and Information Sciences	3,565	9.64	4,575	12.96	5,836	15.17	1.34	1.57
TOTAL	36,968	100.00	35,302	100.00	38,479	100.00	1.00	1.00

Source: Department of Health, Education and Welfare; National Center for Education Statistics, Earned Degrees Conferred.

TABLE 14
RANKINGS OF MASTERATES AWARDED FOR 1977 & 78/1971 & 72 AND
AND FOR 1974&75/1971&72, BY MAGNITUDE OF CHANGE IN PERCENT OF TOTAL

Rank 74&75 / 71&72	Rank 77&78 / 71&72	Field Of Engineering	Ratio 74&75 / 71&72	Ratio 77&78 / 71&72
1	1	Bioengineering and Biomedical Engineering	1.95	2.16
2	2	Environmental and Sanitary Engineering	1.83	1.83
6	3	Engineering Technologies	1.22	1.67
8	4	Engineering, General	1.19	1.61
4	5	Ocean Engineering	1.46	1.60
5	6	Computer and Information Sciences	1.34	1.57
3	7	Materials Engineering	1.47	1.54
10	8	Engineering Physics	1.15	1.33
7	9	Nuclear Engineering	1.21	1.32
9	10	Civil, Construction, and Transportation Engineering	1.16	1.10
13	11	Chemical Engineering	0.94	0.99
15	12	Petroleum Engineering	0.80	0.91
12	13	Agricultural Engineering	0.96	0.90
11	14	Industrial and Management Engineering	0.98	0.88
14	15	Electrical, Electronics, Communication Engineering	0.86	0.85
14	16	Mechanical Engineering	0.86	0.83
14	17	Metallurgical Engineering	0.86	0.66
16	18	Aerospace, Aeronautical, Astronautical Engineering	0.77	0.54
17	19	Engineering Mechanics	0.76	0.53
18	20	Engineering, Other Fields	0.66	0.39

SUMMARY

The whole problem assumes the form of a sizeable shortage of talent for technology that has been piling up over the course of the last decade. Things started going sour at the start of the nineteen seventies when engineering doctorate degree production dropped off both in absolute terms and in relation to the size of the baccalaureate pool.

Helping to depress productivity is student and faculty attraction toward high paying jobs in government and industry and discouragement with lackluster conditions in the groves of academe. Aggravating the situation is a divergence between the increasing inadequacy of the pool of prospective technologists and the pattern of diminishing science and mathematics training at the secondary school level.[7]

It is apparent that these problems create across-the-board challenges in a number of areas: in faculty recruitment and retention, in graduate degree production and accompanying research activity, and in sustaining strong undergraduate programs.

At the same time we find substantial flux creating severe pressure on some fields of engineering and less on others. Staggering burdens are evident in Aerospace Engineering as it struggles to stay off the endangered species list. There is a crisis building in Electrical Engineering that will require strong counteraction. Less apparent, but emergent are similar strains on Chemical Engineering, and Civil, Construction, and Transportation Engineering.

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7 Science and Engineering Education for the 1980's: National Science Foundation and The Department of Education; October, 1980; p. 45-51.

It is against this background that we proceed to review the impact of MEIS on areas to which it relates and to ask what course to chart to accomplish the following:

- Develop strategies for increasing the overall number of masters and doctoral students.
- Create programs for those in industry who have the need to resume studies at the graduate level.
- Produce means with which to counteract harmful economic competition among and between government, industry, and academe.
- Buttress our efforts to work with small colleges and K-12 schools.
- Assess the demand for MEIS educated graduates world-wide.
- Evaluate University of Minnesota graduate productivity vis à vis other U.S. universities.
- Analyze the foreign national composition of the MEIS affected programs and its program impact.
- Predict the impact of 5 new positions each in the Departments of Electrical Engineering and Computer Science on the abilities of those departments to increase their undergraduate enrollment, as well as prediction of the impact of the same new positions on number of graduate student in each of these departments.