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Research Universities for the 21st Century

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Research Universities for the 21st Century

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Abstract

The ***public outcomes*** from research universities are educated students and research that extends the frontiers of knowledge. Measures of these ***public outcomes*** are inadequate to permit either research or education consumers to select research universities based on quantitative performance data. Research universities annually spend over $20 billion on research; 60% of these funds are provided by Federal sources. Federal funding for university research has recently grown at an annual rate near 6% during a time period when other performers of Federal research have experienced real funding cuts. Ten universities receive about 25% of the Federal funds spent on university research. Despite enjoying unprecedented prestige in international circles, numerous studies of U.S. research universities, including those recently conducted by the Carnegie Foundation, are reporting storm clouds. Concerns include balancing research and teaching, the narrow focus of engineering education, college costs, continuing education, and public funding of foreign student education. The absence of research on the ***public outcomes*** from university research results in opinion, politics, and mythology forming the basis of too many decisions. Therefore, we recommend studies of other nations' research universities, studies of various economic models of university research, analysis of the peer review process and how well it identifies the most capable research practitioners and at what cost, and studies of research university ownership of intellectual property that can lead to increased ***public outcomes*** from publicly-funded research performed by research universities. We advocate two practices that could increase the ***public outcomes*** from university research. These are the development of science roadmaps that link science research to ***public outcomes*** and ***public outcome*** metrics. Changes in the university research culture and expanded use of the Internet could also lead to increased ***public outcomes*** from university research. We recommend the use of tax incentives to encourage companies to develop research partnerships with research universities.

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I. Executive Summary

The United States has developed the most extensive research university system in the world. The excellence of this system relative to the education system of other nations is rarely challenged; however, in providing three ***public outcomes*** - education, research, and public service - the appropriateness of the balance in these outcomes is sometimes challenged. A fundamental question is whether or not the publicly-owned and operated component of the U.S. research university system, with the political constraints that public ownership and operation demand, can continue to introduce those improvements that are necessary to sustain the U.S. as the world's only superpower at prices the public can afford. Many are calling for dismantlement of the publicly-owned U.S. research university system and subjecting the entire system to marketplace competition.

The research performed at universities has had profound impact on the evolution of certain industrial sectors, generally new, emerging industries, e.g., information processing and pharmaceuticals. In other sectors, e.g., petroleum and electronics, university research has much less impact. Research universities have tended to focus their research interests on basic research. An option for increasing the research base at universities is to increase research university emphasis on applied research and development.

The relative emphasis of a university on research in comparison to teaching should be entirely driven by the quality of students this university is able to attract. The highest rated universities appropriately emphasize research, perhaps at the expense of teaching, because their students have been prepared for independent study by their K-12 education. However, international competition in math and science for K-12 students suggests that an alarming fraction of high school graduates are not prepared to capitalize on a research university education. Consequently, many research universities must offer remedial education courses. Other evidence of poor K-12 math and science education are international scores and industrial leaders claims that an unacceptable fraction of high school graduates are not prepared for many of the usual tasks required to successfully work for manufacturing and services companies.

Engineering education has always had difficulty providing students with the diversity of knowledge needed for success in an industrial work environment. Engineering education is often singled out for being too narrow; lacking in practice orientation; under emphasis on teaming, management and other skills needed in the work environment; and inattention to continuing education of graduates. The last of these is of particular concern because engineering practice changes rapidly and graduates can quickly lose the skills necessary to contribute in the market place. Accreditation of engineering colleges is shifting to an outcome-based emphasis on the engineering graduate. That is, engineering colleges will be accredited based on the competencies of their graduates, not faculty credentials or curriculum content. We regard this to be an innovative trend that should be continued until accreditation is entirely shifted from the educational institution to the student. In this new accrediting environment, incentives for self study by distance learning will be sufficient to promote continuous education and, finally, degrees will be irrelevant.

At this time, about 50% of those graduating with MS and Ph.D. degrees in engineering and selected areas of science are foreign born. Many of these graduates stay in the U.S. and work for several years after completion of graduate study. This results in a supply of MS and Ph.D. graduates in engineering that exceed market demands by about 20%. While U.S. companies and U.S. graduate schools are advantaged by this, the salary suppression that accompanies this over supply leads to native born Americans being increasingly attracted to career options other than advanced study in engineering. U.S. engineering jobs are slowly being filled by foreign-born graduates of U.S. research universities.

The major concern about university education across all fields of study is rapid cost escalation. Up until 1982, university costs tracked the consumer price index. Since then, costs have grown at two to four times the CPI. Analysis of cost growth indicates that it is driven by lack of incentives to control costs and the inability of consumers to comparatively weigh education costs and benefits. For example, Federal loans to students and Federal subsidies and grants to universities reduces pressure on universities to control costs. In addition, shifting of graduate education costs (50% of graduate education costs in engineering and science are spent educating foreign students) to undergraduate tuition is also driving up the cost of undergraduate tuition. Lack of competition between universities also serves to drive up costs. Perhaps the largest cost driver is the willingness of the public to believe the myth that the quality of university education is determined by its cost. Growth in regulations have also contributed to university cost growth. Distance learning will eventually help to relieve some of the pressure of cost growth on students. To reduce costs, it will probably be necessary for the public to give up operation and perhaps even ownership of universities and focus its attention on testing and accrediting the graduate, not the educational process. The public may still subsidize education, but it should subsidize the student, not the educational institution.

We offer several recommendations intended to improve the public outcomes from U.S. research universities.

1. Research Universities in Other Nations. We should determine how other nations have maximized the ***public outcome*** of their universities' research and identify ways that the U.S. could experiment with these nations' models. We should determine if there is an international precedent for the following as well as other university roles and determine how well other nations' universities have served that role:

- university serves as the nucleus of a regional technopolis;
- university serves as a regional center for technology extension services;
- university serves as a hunter, gatherer, and integrator of innovation made around the world and transfers those innovations to companies in the host country;
- university serves as an R&D center in some area of technology where host Nation's companies are not effectively competing; and
- university serves as an independent, unbiased policy analysis and policy research group.

2. Historical Analysis. We should conduct case studies and synthesize existing studies of past U.S. research university roles and identify which roles have been most and which have been least cost effective in promoting economic growth and other ***public outcomes***. These case studies should include: (I) examination of university-based engineering research centers to determine whether or not these should be further encouraged and promoted, (ii) comparison of the long-term economic return from basic research to applied engineering research, (iii) sector-to-sector comparison of the private and public or social return of university research that supports major industrial sectors to determine which sectors are most affected by university research, and (iv) identification of the stage of evolution of the industrial sector where university research has the highest value.

3. Most Capable Practitioners. Vannevar Bush argued that most of the significant progress in a scientific field is generated by a relatively small group of the most capable practitioners. We should conduct selected case studies of university research and quantitatively assess how well this premise holds today, and, if it does hold, recommend how this should impact the distribution of federal research funds to universities.

4. Peer Review. Many studies have lauded the peer review process that is often used in selection of research proposals submitted to the Federal government by universities. Others see peer review as dominated by a megaresearch university oligopoly that does not welcome new members. Still others argue that the quality of university research is less important than its teaching value. The U.S. should make an **objective, quantitative** analysis of the peer review process, examine the ***public outcome*** from other alternatives for distributing federal research funds, and make recommendations to Congress regarding the importance of peer review in assuring that the value of ***public outcomes*** well exceed public costs. The social cost of preparing unfunded proposals must be included in this analysis.

5. Teaching Versus Research. University administrators often laud the value of research in teaching. Others argue that as university research has grown, undergraduates are increasingly taught by graduate assistants and other irregular faculty, research takes precedence over teaching, the number of students in the classroom grows, and the costs of undergraduate education are increased to finance graduate school research. An objective, competent U.S. institution with no vested interest in the outcome should make a quantitative, cost-benefit assessment of the impact of university research on the cost and quality of undergraduate education.

6. IP Ownership. We should examine the practice of universities owning intellectual property gained through federal funding of university research and determine if this practice serves the long-term interest of the U.S. public.

7. Science Roadmaps. It has been proposed that federally funded U.S. research should be based on science roadmaps. Others have argued that all federal research should be strategic in design with an expected or potential path to ***public outcome*** identified prior to conducting the research. We should assess the value of science roadmaps and strategic research for federally funded science research and, if they show promise for increasing the ***public outcome*** from university research, recommend a process to Congress and the President for how science roadmaps and assurance of strategic content could be integrated into National innovation policy.

8. Research Culture. In recent years corporate management of R&D has undergone many changes with industrial research groups having to constantly reinvent themselves. In the meanwhile, university research has changed relatively little with many researchers studying the same topic throughout their entire career in academe. We should examine the university research culture and identify how it can be changed to produce graduates that are better prepared to contribute in an industrial environment.

9. Research and Immigration. Federally-funded university research should not be a vehicle for making careers in engineering and science unattractive to ***U.S. citizens***. We recommend that the pros and cons of Congress giving preference to federal R&D funds that support research by faculty and graduate students that are ***U.S. citizens*** be determined.

10. Metrics. We recommend that Congress and the President increase expectations of ***public outcome*** from all universities that perform federal R&D and institute metrics to measure ***public outcome***. Federal agencies that fund university research must be organized and managed so that those university researchers that maximize the ratio of ***public good*** to public cost in the execution of their research are rewarded by budget growth and those that are not successful are penalized. To accomplish this, government must recognize and refuse to accept anecdotal evidence of success from performers of all federal R&D and shift to a ***public outcome***, metrics-based evaluation system.

11. Tax Incentives. We recommend that Congress and the President offer tax incentives for companies to form partnerships with universities for those cases where it can be shown that the potential for ***public good*** accruing from the partnership exceeds the reduction in lost tax **revenue**.

12. Internet Education. We recommend that Congress institute a program to study the relative benefits of an Internet-based or satellite-based education system and, if this system shows promise, propose roles for the federal government to play in promoting its development and use.

II. Introduction to Research Universities

A. What Is a Research University?

a. The beginning. In the 11th century the first universities were founded in Bologna for the purpose of studying Roman law and in Salemo for the purpose of studying medicine. Recognition of the benefits of university education slowly grew and a century later universities were established at Paris and Oxford.[3] Midway through the 19th century J. H. Newman, creator of Catholic University in Dublin and noted for his essays on the purpose of the university, provided an early view of a university education,

> *He (the university student) profits by an intellectual tradition, which is independent of particular teachers, which guides him in his choice of subjects, and duly interprets for him those which he chooses. He apprehends the great outlines of knowledge, the principles on which it rests, the scale of its parts, its lights and its shades, its great points and its little, as he otherwise cannot apprehend them. Hence it is that his education is called "Liberal". A habit of mind is formed which lasts through life, of which the attributes are freedom, equitableness, calmness, moderation, and wisdom; or what in a former Discourse I have ventured to call philosophical habit. This then I would assign as the special fruit of the education furnished at a University, as contrasted with other places of teaching or modes of teaching.*[4]

When Johns Hopkins University opened its doors in 1876, the American research university, modeled after the German graduate university, was born. However, it wasn't until after World War II that the American research university began to grow in size and gain respect among the intemational community of scholars. Today, American research universities are considered to be the world's best. Graham and Diamond point out,

> *Whether measured by the distribution of Nobel prizes, by international applications for student admissions and faculty appointments, or by reputational surveys, the prestige of America's universities has soared since World War II.*[5]

The research university has a tripartite mission: teaching, research, and public service. In contrast to the comprehensive university whose mission is to teach a wide spectrum of students and prepare them for a wide spectrum of careers, the modem research university carries the added responsibility for knowledge generation.[6]

b. Liberal or specialized education? Since the beginning of the nineteenth century, debate and controversy have surrounded the purpose and function of the university. Much of this debate stems from contrasting beliefs regarding the virtues of liberal leaming in comparison to attaining useful, practical knowledge. For many, liberal education is considered to be an end worthy of pursuit without consideration of vocational utility. Turner points out,

> *Argument that university study should eschew usefulness has produced another unexpected, harmful result for the life of modem universities - the absence of a clear understanding and articulation of mission. ... Trustees, alumni, and the general public too often assume that faculties and administrators are by nature or disposition*

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[3] The Economist, The Knowledge Factory, Octover 4, 1997, p. 3.

[4] May Yardley, editor, Select Discourses From The Idea of a University: Landmarks in the History of Education, Cambridge at the University Press, 1931, p. 26.

[5] Hugh Graham and Nancy Diamond, The Rise of American Research Universties, The Johns Hopkins University Press, 1997, p. 1.

[6] Jan Sinnott and Lynn Johnson, "Reinventing the University: A Reasonable Proposal for a Problem-Focused University for the 21st Century", Futures Research Quarterly, Winter, 1996, p.62.

unconcerned about the so-called real world. ... Argument for uselessness has become a rationalization for academic inefficiency and the consequent rise in costs to students.[7]

Universities have strayed far from the concept of a liberal education and in recent years have become increasingly focused in both their education pursuits and the research pursuits of their faculty. In the sciences the geometric growth rate of scientific knowledge has led research universities to abandon a broad education. Wilson has recently articulated the demise of the liberal education.

During the past thirty years the ideal of the unity of learning, bequeathed to us by the Renaissance and the Enlightenment, has been largely abandoned. With rare exceptions American colleges and universities have dissolved their curricula into a slurry of minor disciplines and specialized courses. ... only a third of colleges and universities require students to take at least one course in the natural sciences. ... true reform will aim at the consilience of science with the social sciences and the humanities in scholarship and teaching.[8]

While many praise U.S. universities for their excellence in education, there is a growing uneasiness among the public that something is wrong with our universities and the education they are offering their graduates. Sinnott and Johnson point out,

We are moving from a postmodern age to an age of chaos-complexity consciousness. At the same time we are feeling that our universities have lost touch with their populist ideals for which they are substituting elitist tendencies. ... We seem to have had difficulty deciding whether the purpose of the university is the cognitive development of adults, moral education, preparation for professions, conveyance of broad cultural knowledge, furtherance of the academic tribes with teaching as a side activity to finance the enterprise, or some other purpose. ... All the levels of higher education are criticized for failing to teach their students to think well, and for "dumbing down" the curriculum rather than nurturing complex thought, critical thinking, wise thinking, or even analytic and synthetic thinking, not to mention sophisticated personal development.[9]

Gelb is equally critical,

In most cases, schooling does not develop originality, delight in ambiguity, or self-expression. Rather, the thinking skill that's rewarded is figuring out the "right answer" - that is the answer held by the person in authority, the teacher. This pattern holds through university and postgraduate education, especially in a class where the professor wrote the text. ... Our way of testing and grading reinforces a pernicious pattern of short-term, superficial thinking. ... The fear-based, authority-pleasing, rule-following approach to education may have served to provide society with assembly-line workers and bureaucrats, but it does not do much to prepare people for the world as it is today.[10]

Of course, most real world problems are multidisciplinary and much of modem innovation occurs at the intersection of multiple disciplines. The modem university graduate, especially those majoring in a field of science, has little grasp of the "big picture", and often doesn't recognize the extreme narrowness of their education. Much of this specialization stems directly from pressure on faculty to conduct scholarly research. Wilson explains,

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[7] Frank M. Turner, "Newman's University and Ours", essay in The Idea of a University, Yale University Press, 1996, edited by Frank M. Turner.

[8] Edward O. Wilson, "Back From Chaos", The Atlantic Monthly, March, 1998, p. 62.

[9] Jan Sinnott and Lynn Johnson, "Reinventing The University: A Reasonable Proposal for a Problem-Focused University for the 21st Century", Futures Research Quarterly, Winter, 1996.

[10] Michael J. Gelb, Thinking for a Change, Harmony Books, 1995, p. 8.

Precisely because scientific information was increasing at a geometric pace most researchers thought little about unification, and even less about philosophy. ... another, humbler reason for the lack of interest in the big picture: scientists simply didn't have the requisite intellectual energy. The vast majority of scientists have never been more than journeymen prospectors. That is truer than ever today. They are professionally focused; their education does not open them to the wide contours of the world. ... The most productive scientists, installed in million-dollar laboratories, have no time to think about the big picture, and see little profit in it. ... The faculties of higher education around the world are a congeries of experts. To be an original scholar is to be a highly specialized world authority in a polyglot Calcutta of similarly focused world authorities. ... To be a successful scholar means spending a career on membrane biophysics, the Romantic poets, early American history, or some other such constricted area of formal study. ... A balanced perspective cannot be acquired by studying disciplines in pieces; the consilience among them must be pursued.[11]

While the world needs generalists than can integrate knowledge across multiple disciplines to synthesize solutions to the problems that are especially important to the public, research universities are producing graduates and faculty so specialized that they can only analyze problems so narrowly defined that they bear little resemblance to issues of concern to the public.

III. Research University Outputs

A. Research

a. Funding - input distribution. All research universities conduct research; however, as the data shown in Table I illustrates, much of the Federal support for university research is biased toward a relatively small group of universities[12] and these universities are disproportionately private. Graham and Diamond argue that private research universities derive great advantage over public universities through their affluence and they have had entrepreneurial freedom not experienced by public universities constrained by public bureaucracies and state regulation. They also conclude that the presence of a medical school on campus greatly advantages the ability of a university to obtain research funds.

Data compiled by Graham and Diamond suggest that public research universities in California and New York have benefited from the competition derived from the state having several research universities.[13] Curiously, many governors and state legislatures take major steps to avoid having redundant capabilities in state universities located within their state. In doing so, they create state level monopoly institutions that do not compete well at the National level.

The narrowness of the funding distribution calls into question the fundamental purpose of funding research at research universities. If the fundamental purpose is the research outcome, then it is appropriate that research funds be concentrated among only those universities that conduct the highest quality research. If the purpose is the education value of research, then research funds should be widely distributed over all research universities. Ironically, many of the elite universities adopt both sides of this argument. When competing with companies and Federal laboratories for Federal research funds, they argue that the Federal government should concentrate its research funds in universities because of the educational value of research. When competing with other universities for Federal research funds, they argue that university research funds should be concentrated among the highest quality research performers because of the value of the research.

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[11] Edward O. Wilson, "Back From Chaos", The Atlantic Monthly, March, 1998, p. 56.

[12] Science and Government Report, In Academic Research Funding, the Rich Get Richer, Nov., 1996.

[13] Hugh Graham and Nancy Diamond, The Rise of American Research Universities, The Johns Hopkins University Press, 1997, p.7.

Table I: Distribution of Federal funding of university research among the leading research universities. The rank columns are the ranks of these schools in terms of receipt of Federal funds in 1980 and 1994. Also shown in parenthesis after each school is the U.S. News ranking of each school. U.S. News ranks the top 50 schools numerically and the remaining schools by tier 2 (T2) and tier 3 (T3). There are various other ranking schemes that have been applied to universities[14].

rank '94	University	M$	rank '80	rank '94	University	M$	rank '80
1	Johns Hopkins (15)	612	1	26	U. of Rochester (30)	108	26
2	U. of Washington (42)	276	4	27	U. of Alabama-B'hm (T3)	104	45
3	MIT (5)	267	2	28	U. of Texas-Austin (T2)	103	28
4	Stanford (6)	262	3	29	U. of Chicago (12)	102	17
5	U. of Michigan (24)	240	12	30	Northwestern U. (9)	100	38
6	UC-Los Angeles (31)	222	6	31	Case Western Res. (38)	99	39
7	UC-San Diego (34)	218	5	32	UC-Davis (40)	99	24
8	U. of WS-Madison (41)	207	9	33	Baylor Med. Sch. (T2)	98	37
9	UC-San Francisco (T3)	204	15	34	U. of Iowa (T2)	94	32
10	Cornell (14)	194	10	35	New York U. (35)	92	29
11	U. of Pennsylvania (13)	190	13	36	Ohio State U. (T2)	92	30
12	Harvard (4)	190	7	37	Vanderbilt U. (20)	87	48
13	Columbia (11)	187	8	38	U. of Utah (T2)	85	36
14	Penn State (T2)	184	20	39	Cal. Inst. of Tech. (9)	84	33
15	Yale (1)	183	14	40	U. of Miami (T2)	83	42
16	U. of Minnesota (T2)	180	11	41	Indiana U. (T2)	83	47
17	U. of Colorado (T2)	166	22	42	U. of MD-College Pk. (T2)	80	46
18	Duke U. (4)	154	23	43	Purdue U. (T2)	78	31
19	U. of Pittsburgh (T2)	153	35	44	Boston U. (T2)	78	50
20	U. of Southern Cal.	150	21	45	U. of Virginia (21)	76	
21	Washington U (17)	150	16	46	Emory U. (19)	75	
22	UC-Berkeley (27)	149	19	47	U. of Florida (T2)	73	49
23	UNC-Chapel Hill (25)	146	25	48	Texas SW Med. (T2)	72	
24	U. of Arizona (T2)	144	34	49	Yeshiva U. (45)	71	27
25	U. of Illinois-Urbana (50)	119	18	50	Louisiana State U. (T3)	68	

In 1995, U.S. universities spent $21.6 billion, or 12.6% of the U.S. total expenditure on research and development. Slightly over 60% of these university funds were provided by the Federal government. (In comparison, in the mid-1930s, about 10% of university research funds came from Federal grants, but by 1980, the Federal government provided 68% of university R&D funds.) Over the past 15 years U.S. universities have averaged increasing their Federal R&D budget by 5.8% each year. In comparison, FFRDCs have increased spending by 2.8% each year, industrial laboratories have increased spending by 1.4% each year, and government-operated laboratories have increased funding by 0.7% each year. Over this 15 year period, only universities have experienced real growth in R&D spending. Although universities have increased their Federal R&D funding by 5.8% per year, this growth rate has not been adequate to fund university cost growth which been about 6% per year.

Generally the ten universities that receive the most Federal research money get about one-fourth of the federal funds for research spent at universities and the top 50 receive slightly

[14] For additional ranking data, see, for example, Hugh Graham and Nancy Diamond, The Rise of American Research Universities, The Johns Hopkins University Press, 1997.

less than two thirds of federal funds spent for all university research. In 1980, when federal funding for university research was $4.1 billion, (1980 dollars) the top 10 universities received $1 billion or 24% of Federal research funding at universities and the top 50 received 64% of Federal research funding at universities. In 1994, Federal funding for university research was $11.7 billion (1994 dollars) and the top 10 universities received $2.7 billion or 23% of Federal research funding and the top 50 universities received 63% of Federal research funding at universities.

Over a period of 15 years, those universities that received the most Federal funding have generally remained unchanged. A few exceptions are worthy of noting. The University of Michigan has risen from 12th place to 5th place; the University of California at San Francisco has risen from 15th to 9th; The University of Pittsburgh has risen from 35th to 19th; The University of Alabama at Birmingham has risen from 45th to 27th; and Vanderbilt University has risen from 48th to 37th. These data illustrate that universities can, with effort and perhaps strong political support, increase their ranking among those universities that receive the most Federal R&D support

b. Types of research performed at research universities. As the data in Table II illustrates, universities perform more basic research for the Federal government than any other class of R&D performer. However, universities are not yet major players in conducting engineering development work for the Federal government.

To substantially increase their Federal research funding base, universities have five options:

- Universities may persuade the Federal government to shift funds from applied research and development to basic research. The possibility of again doubling the budget of the National Science Foundation without making Federal R&D cuts in other areas is unlikely. Shifting the Federal R&D portfolio from development to basic research means reducing current emphasis on defense and other issues of direct public interest.

- Universities may focus their basic research interests in areas where intellectual property (IP) is most easily protected by patents and copyrights, e.g., pharmaceuticals and agriculture chemicals, and use the royalty payments from licensing of intellectual property to fund research. Some companies, e.g., IBM, Texas Instruments, etc., have turned intellectual property into a revenue stream sufficient to pay for over 20% of the companies' annual investment in R&D. With the exception of MIT, Wisconsin and Purdue, few universities have turned intellectual property (IP) into a revenue stream that covers the cost of IP administration.

- Universities may shift research interests from the basic sciences to engineering development and forge partnerships with Federal laboratories and companies to gain access to development problems, development funding, and development facilities. If, for example, universities increased their fraction of Federal development funds from 3% of the Federal development budget to 24% of the Federal development budget, universities would experience a 73% increase in Federal R&D funds. This shift in emphasis would likely lead to a dramatic increase in company support for university R&D because it would shift the university culture toward applications. Mansfield has determined from his studies that academic researchers whose work is cited by companies as contributing to their new products and processes frequently or predominately work on academic research projects that spin-off from their consulting for industry.[15] Mowry interprets Mansfield's research to suggest that the peer review

[15] Edwin Mansfield, "Contributions of New Technology to the Economy", in Technology, R&D, and the Economy, edited by Bruce R. Smith and Claude E. Barfield, The Brookings Institution and American Enterprise Institute, Washington, DC, 1996, p 137.

system used for distribution of Federal R&D funds at universities has limited utility for industry-relevant research.[16]

Table II: Distribution of Federal R&D to universities according to funding category. HHS - Department of Health and Human Services, and NSF - National Science Foundation, DoD - Department of Defense.

Type of R&D	Millions of Dollars ($)	% of Federal Budget	Primary Agency Source	Secondary Agency Source %
Basic Research	7,497	53%	HHS-52%	NSF-22%
Applied Research	3,343	24%	HHS-59%	DoD-11%
Development	1,257	3%	HHS-52%	DoD-29%
Total	12,097	17%	HHS-54%	NSF-15%

- Universities may persuade Congress that although U.S. companies are currently quite competitive, their research time horizons are too concentrated on short-term goals and unless universities are funded to conduct long-term research, U.S. companies will lose their competitiveness and the U.S. economy will suffer. (This argument is well-stocked with unsupported assumptions; nevertheless, many believe on faith that the U.S. is under-investing in long-term R&D.) Companies believe that the factor most likely to impact their competitiveness in the coming decade is education and skill level of the workforce and they recommend that the Federal government treat education policy and the budget deficit with the highest priority.[17]

- Universities may develop partnerships within universities between the physical sciences, social sciences, law, economics and business that can be used to attack this Nation's real problems.

c. Industrial impact of university research. For all of the discussion regarding the value of university research in promoting economic growth, little meaningful policy-related research has been done. Mansfield notes that although most industrial innovation has been made by engineers and scientists that work for companies, university research has also contributed to the development of industrial products and services. Surveys of seventy-six firms in seven industrial sectors to determine the role of recent academic research (within 15 years of commercialization) yield the data shown in Table III.[18]

Considering that universities only conduct about 12% of the research in the U.S., considering that much of it is in areas such as astronomy or anthropology that have relatively weak linkages to industrial use, and considering that it is concentrated on basic research, leads to the conclusion that the mean returns for products and processes are impressive. Despite that, we believe that the commercial potential of university research is far greater than what has been achieved. It should be clear that academic research is having a major impact on information processing, pharmaceuticals, and metals sectors, but it is having little impact on the petroleum, instruments, electronics, and chemicals sectors. These data suggest that academic research has had its largest impact in the newest sectors where products and processes are the easiest for a single researcher to master and intellectual property is the

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[16] David C. Mowery, Comments on "The Private and Social Returns to Research and Development" by Bronwyn H. Hall and "Contributions of New Technology to the Economy" by Edwin Mansfield, in Technology, R&D, and the Economy, edited by Bruce R. Smith and Claude E. Barfield, The Brookings Institution and American Enterprise Institute, Washington, DC, 1996, p 169.

[17] Council on Competitiveness, Competitive Index 1996: A Ten-Year Strategic Assessment, October, 1996.

[18] Edwin Mansfield, "Contributions of New Technology to the Economy", in Technology, R&D, and the Economy, edited by Bruce R. Smith and Claude E. Barfield, The Brookings Institution and the American Enterprise Institute, 1996.

easiest to protect. In older industrial sectors where technology is complex and cannot be mastered by a single researcher and intellectual property is more difficult to protect, innovations are almost entirely driven by engineering advancements rather than scientific discoveries. For universities to increase their impact in these sectors, they would have to shift their research interests from the basic sciences to engineering and they would have to partner with companies and Federal labs.

Table III: The role university research in various industrial sectors. Academic research seldom directly results in the invention of a specific product or process, rather it often yields new models of technology that prove to be critical in developing new products and processes. Most analysis of the ***public return*** from academic research, not including its teaching value, suggest that it is about two times the private return.

	Percentage of Industrial products and processes that were developed with very substantial aid from recent academic research.	
Industry	**Products**	**Processes**
Information Processing	17%	16%
Electronics	3%	4%
Chemical	4%	4%
Instruments	5%	1%
Pharmaceuticals	17%	8%
Metals	9%	9%
Petroleum	1%	1%
Mean	8%	6%

Randazzese's research on computer aided design (CAD) tool transfer from the Semiconductor Research Corporation (SRC) sponsored facility at Carnegie Mellon University to SRC members highlights the difficulties encountered in transferring university research in fast-moving fields such as integrated circuit design. Randazzese points out that university CAD research often arrives in industry in the form of graduate student developed software that is not very well engineered, is somewhat oversold, and is untested on industrial scale problems. He observed that company adaptation of university CAD research for commercial application only succeeds through structured, managed, and usually costly activities by company adopters. Adopter costs may be ten times higher than was invested in the original university research. Unless companies are willing to make these adopter investments and provide incentives to their employees to adopt and implement university CAD tool innovation, the technology transfer process is likely to fail.[19]

B. Science and Engineering Graduates

a. Introduction. To understand the education of scientists and engineers at research universities requires that one first review the role of the scientist and engineer in society then evaluate their education based on how well it prepares graduates to fill this role. Vannevar Bush had a model of engineers that contrasted with scientists.

> *The engineer is not primarily a physicist, or a business man, or an inventor, but someone who would acquire some of the skills and knowledge of each of these and be capable of successfully developing and applying new devices on the grand scale. ... The engineer is both a scientist and a businessman. Engineering is a scientific profession, yet the test of the engineer's work lies not in the laboratory, but in the marketplace.*[20]

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[19] Lucien P. Randazzese, "Exploring University-Industry Technology Transfer of CAD Technology", IEEE Transactions on Engineering Management, November, 1996, pp 393-401.

[20] G. Pascal Zachary, "Vannevar Bush on the Engineer's Role", IEEE Spectrum, July, 1995, pp 64-69.

Since World War II, there has been a debate regarding the relative emphasis of science and mathematics in a research-based curriculum in comparison to the emphasis provided by the hands-on art of engineering design as well as an emphasis on education in business, economics, leadership, management, and the social sciences. Emphasis on math and science is supported by the argument that graduates must be offered an education that can prepare them for a 40 year career and math and science are static relative to most technology change. An extreme emphasis on technology education would have a half-life of little more than 5 years for most engineering disciplines and many engineering faculty argue that it would put them in the vocational education business. (A 1996 report to the National Academy of Engineering cited 1987 half-lives of mechanical engineering knowledge to be 7.5 years, electrical engineering to be 5 years, and software engineering to be 2.5 years.[21] As we enter the 21st century, these half lives have further decreased.)

b. Scientific Research Education. Ideally, a research education should give heavy emphasis to science and mathematics but blend into the teaching of these scientific disciplines their application to contemporary engineering issues while simultaneously integrating economics, management and social issues that are also important to technology. In addition, a research education should impart in a student the ability to express herself through writing in a clear, logical manner, and through a verbal argument which provides pros and cons of a proposition and concludes with a clear choice of the options. Finally, the research university student should be able to interact with peers and supervisors, work with others to solve a common problem, and understand real limits imposed by economic constraints. Perdowitz points out,

> *Students are correct when they call for multidisciplinary education, even beyond the mixing of scientific disciplines, to the mixing of scientific training with work in the humanities or the social sciences. Only the next level of university governance can overcome departmental barriers and make such education possible - a difficult task where I have yet to see much progress.*[22]

The intellectual and institutional barriers to doing all of this are profound. Many university practices inhibit such an integrated curriculum or systemic approach to education. For example, universities' emphasis on research demands preference for the specialist over the generalist that might be able to contribute to this educational breadth. Other inhibitors include universities preference for young, narrowly-focused career faculty and administrators over experienced professionals that have had a career in industry and have developed a grasp of the "big-picture", universities relatively low regard for faculty writing precollege textbooks, and turf wars between different university departments. These inhibitors lead to an impractical solution - several separate courses in mathematics, physical sciences, economics, management, etc., each taught by a different department of the university addressing each issue piecemeal. Bordogna points out,

> *Most curricula require students to learn in unconnected pieces - separate courses whose relationship to each other and to the engineering process are not explained until late in a baccalaureate education, if ever. Further, an engineering education is usually described in terms of a curriculum designed to present to students the set of topics engineers "need to know", leading to the conclusion that an engineering education is a collection of courses. The content of the courses may be valuable, but this view of engineering education appears to ignore the need for connections and for integration - which should be at the core of an engineering education. ... The complementary curricular components of a holistic undergraduate curriculum lead to a practice-oriented master's level curriculum and/or an integrative, discovery-focused*

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21 Ernest T. Smerdon, "Lifelong Learning for Engineers: Riding the Whirlwind", National Academy of Engineering Conference on Career-Long Education for Engieers, Washington, DC, 1996.

22 Sidney Perkowitz, "Moving the Goalposts", Amercian Scientist, September/October, 1996, p. 427.

doctoral curriculum - all supported by infrastructures for cognitive systems and career-long learning.[23]

The need for integration and breadth in education can probably only be met by major publicly-supported efforts to team-develop courses complete with electronic texts that incorporate these multiple disciplines in complementary ways. The development of next generation electronic textbooks is a challenging issue that is key to addressing the multidisciplinary skills companies are recommending for their staff.

James Madison University (JMU) is pioneering an interdisciplinary, integrative approach to science and technology as a holistic education process which gets away from the idea of departments and specialized curricula to create a new concept of the liberally educated person. George Mason University has created a new virtual college that has abandoned traditional structures like seat time, credit hours and campus attendance.

c. Engineering Education.
Analysis. Unlike other professions such as law, medicine, dentistry, etc., in which professional stature is attained only after graduate and post graduate study and examination, engineering education attempts to develop professionals after only four years of undergraduate study. In most universities, however, the average engineer completes her degree requirements only after about five years of study. Not surprisingly, employers of engineers are rarely satisfied that this ambitious goal has been achieved even after five years. National committees, with strong influence by U.S. companies, usually recommend undergraduate education programs that not only prepare engineers for a lifetime career in engineering design, but strengthen their written and oral communication skills while also preparing them for second careers in management as well as permit them to pursue graduate degrees in law, medicine, engineering, and public policy.

Among these various studies of engineering education, a study conducted jointly by the Engineering Deans Council, the Corporate Roundtable, and the American Society for Engineering Education is perhaps the most comprehensive.[24] This study identified the following action items for engineering colleges:

- Each engineering college should identify the constituencies it serves, establish a clear institutional vision, define its mission through a conscious examination of the school's current activities and comparative advantages, set future strategic directions, and identify goals.

- Engineering colleges should develop a plan within the context of the institutional vision that identifies objectives and milestones for reaching the objectives. This plan should be periodically reviewed both internally and by constituents.

- The faculty reward system must support the institutional goals.

- The curriculum must incorporate teaming skills, communication skills, leadership development, a systems perspective, appreciation of diversity, a multidisciplinary perspective, commitment to TQM, undergraduate research and engineering experience, ethics training, and an understanding of the social, economic, and environmental impacts of engineering decisions.

- Federal agencies that fund education should help universities and their industrial partners identify creative approaches to lifelong learning by funding pilot projects and experiments.

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[23] Dr. Joseph Bordogna, Acting Director, National Science Foundation, keynote speech, NSF Engineering Innovators' Conference, April 8, 1997.

[24] Engineering Science Council, Corporate Roundtable, and American Society for Engineering Education, Engineering Education for a Changing World, 1994.

- Advanced degree programs must include practice-oriented degrees, e.g., engineering systems, finance and accounting, technology policy, management and decision making. Courses should include team based activities and should include other university departments and industry.

- Engineering colleges should develop innovative ways of providing continuing education to practicing engineers.

- Engineering colleges should partner with at least one local K-12 school to improve math and science education, provide role models, and increase understanding of engineer's roles in society.

- The federal government should develop a National program to foster creation of industrial professorships in engineering colleges.

- Engineering colleges should develop reciprocal exchange programs with local and regional corporations.

- Deans should encourage faculty to participate in research, educational, and leadership activities beyond the engineering college in business, medicine, arts, sciences, and education departments.

- Professors should encourage students to participate in university-wide activities including student government, professional societies, athletics, performing arts, debate, study abroad, and other activities.

- Engineering colleges must help non-engineering majors better understand the importance of technology in their lives.

- Federal agencies that fund research should explore ways of encouraging educational institutions, research organizations, federal laboratories, and industry to share resources.

- Federal funding for science and technology should be allocated in open competition based on peer review.

- Universities, industries and federal agencies should develop flexible and negotiable policies regarding intellectual property.

Philip Condit, president and CEO of Boeing and R. Byron Pipes, president and CEO of Rensselaer Polytechnic Institute, correctly observe that most of the reports on engineering education call for little more than minor adjustments or additions to current programs. These gentlemen convened a brainstorming summit of leading industrialists and educators to examine the forces affecting the engineering profession and to develop a new model of engineering education that will meet the needs of companies and the global engineer. Three basic principles of engineering education emerged from this summit.

- Universities must follow industry and locate branch campuses close to industrial customers around the world.

- Engineering education must provide continuous learning experiences for their graduates that accounts for the broader knowledge base that engineers require as they mature.

- Standards for engineering education will become increasingly important.

Condit and Pipes point out,

A tendency toward specialization may occur as institutions focus, for marketing and economic reasons, on their core competencies. Franchising of educational programs by an institution, either to commercial service providers or to other universities, is one possible response to this specialization. Collaboration on the granting of academic degrees by universities will increase at the same time that emphasis on degrees by industrial employers will diminish. ... As the demand by industry for this new dimension of educational support grows, those universities that adapt to meet the demand will thrive; those that do not will become less and less relevant Over time, then, it is likely that the number of academic engineering programs in the United States will decline. ... Global engineering is already a reality. Engineering education and the education system must adapt to that reality.[25]

It has been much easier to identify weaknesses in engineering education than to develop a National course of action that effectively addresses these issues and actually leads to curriculum reform and cultural change. Often forgotten in these studies is that colleges of engineering are only one of many colleges in a university and that the culture and practices of the engineering college are influenced by these colleges. Engineering is a practitioners discipline with strong ties to industry. Most of the other colleges and departments in universities have weaker industrial ties, e.g., english, history, psychology, social studies, education, etc. Therefore, in many ways engineering education runs orthogonal to most of the educational disciplines offered by research universities.

Accreditation. Since 1933, the Accreditation Board for Engineering and Technology (ABET) has been the sole body responsible for accreditation of educational programs leading to degrees in engineering. Up until recently, ABET accreditation was based almost entirely on faculty credentials, curriculum content, and college resources. Little attention was devoted to assessment of student competence. The ABET accreditation process is designed to assure that graduates of an accredited program are prepared adequately to enter and continue the practice of engineering. The process stimulates the improvement of engineering, encourages new and innovative approaches to engineering education, and identifies these programs to the public.

Engineering colleges may elect to have their programs evaluated by ABET under current criteria, or in a revolutionary break from tradition, they may choose to have them evaluated under new ABET criteria termed Engineering Criteria 2000. The latter emphasizes TQM, strategic planning, and outcome-based analysis. To be accredited under Engineering Criteria 2000, programs must meet criteria regarding student performance after they graduate, they must have established program educational objectives, they must identify and assess program outcomes, they must stress the professional component, their faculty must satisfy competence criteria, their facilities must be adequate, their financial and leadership resources must be adequate, and each program must satisfy applicable program-specific criteria. Of particular interest are program outcome and assessment criteria. These are outcome based criteria based on the capabilities of graduates, not the processes used by the engineering college. To qualify, the engineering program must have a graduate assessment process with metrics identified and it's programs must demonstrate that their graduates have the following qualities:

- an ability to apply knowledge of mathematics, science, and engineering;
- an ability to design and conduct experiments, as well as to analyze and interpret results;
- an ability to design a system, component, or process to meet desired needs;

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[25] Philip Condit and R. Byron Pipes, "The Global University", Issues in Science and Technology, Fall, 1997, pp. 27-28.

- an ability to function on multi-disciplinary teams;
- an ability to identify, formulate, and solve engineering problems;
- an understanding of professional and ethical responsibility;
- an ability to communicate effectively;
- the broad education necessary to understand the impact of engineering solutions in a global and societal context;
- recognition of the need for, and an ability to engage in life-long learning;
- a knowledge of contemporary issues; and
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.[26]

We see this outcome-based assessment as an important and critical step in directing accreditation away from a focus on the educational process, curriculum and faculty to emphasize the outcomes it has on graduates. We believe that accreditation should eventually shift entirely to accreditation of the graduate, as the bar examination has done for lawyers, and board certification has done for medical doctors. This is a necessary step, if life-long learning and distance education are to become a new paradigm. Miller and Dunn[27] point out that the virtual university will lead universities and colleges to certify learning through extensive testing services, and credit will be given to those who have learned through their experiences and self-directed study. These scholars note,

> *If the virtual university is to be fully realized, it is imperative that higher education be deregulated. Deregulation will lead to a more flexible and viable higher education industry. Most current regulation comes from the U.S. Department of Education and the various agencies that accredit colleges and universities. At present, accreditation in the United States is a private, peer based, self-regulating, modestly conservative process. Primary accreditation is regional in nature which leads to significant differences in standards across the country. By and large there is general reluctance on the part of educational institutions to reveal accreditation study results except for the positive aspects of such reports. The general public has little input into quality control, nor are there good measures for the public to use to determine the quality of a specific college's programs.*

The National Science Foundation has also established the Engineering Education Coalitions (EEC) program to work on engineering education reform. Each of eight coalitions has been established at a group of universities that attempts to implement eight separate themes of engineering education reform. Thus, each coalition has its own set of objectives with NSF providing an overarching set of goals for all of the EEC coalitions.[28] Seven years after the establishment of the EEC program, it has produced many outputs, but it is unclear that engineering schools not part of the coalition have actually benefited from its efforts. Thus, like many efforts of government and academe, the outputs (paperwork, meetings, feel-good proclamations, etc.) are impressive but, the ***public outcomes*** are not.

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[26] The Accreditation Board for Engineering and Technology, Engineering Criteria 2000, second edition, 1997.

[27] Myron M. Miller and Samuel L. Dunn, "From the Industrial to the Virtual University", Futures Research Quarterly, Winter 1996, pp. 71-84.

[28] Robert J. Coleman, "The Engineering Education Coalitons: A Progress Report", American Society for Engineering Education Prism, , September 1996, pp24-31.

IV. Conflicts in Research University Education

A. Immigration in Engineering

a. Importance of engineers. Dr. Joseph Bordogna, Acting Deputy Director of the National Science Foundation, and President of the Institute of Electrical and Electronics Engineers, describes the importance of engineers to America's future,

> *The true wealth of a nation resides in its human capital - especially its engineering workforce. Engineers will develop the new processes and products and will create and manage new systems for civil infrastructure, manufacturing, health care delivery, information management, computer-communications, and so on. In general, they will put knowledge to work for society - and in doing so, enable a huge potential for the private sector to create wealth and jobs. ... The essence of engineering is the* ***process of integrating all knowledge to some purpose.*** *As society's master integrators, engineers must have the functional background to provide leadership in nurturing the concurrent and interactive process of innovation and wealth creation. The engineer must be able to work across many different disciplines and fields -- and make the connections that will lead to deeper insights, more creative solutions, and getting things done.*[29]

If engineers are, as Dr. Bordogna so eloquently stated, so important to our Nation's wealth, do we want to stock the U.S. engineering workforce with the best and brightest from around the world, or do we want to cultivate engineering as a profession that Americans find to be an attractive and satisfying career option? We are currently emphasizing the former at the expense of the latter.

b. Engineer's salaries and employment demand. While much has been written about the problems of a research-based education, far less has been written about the lack of economic incentives for pursuing a Ph.D. in science and engineering and how that impacts U.S. citizens interest in attending graduate school.

Too many federal agencies lack the courage to examine this issue and when they have made the effort, results are often unsatisfactory. We cite, for example, NSF efforts in the early 1990s to perpetuate the notion that the U.S. was headed for a major shortfall in science and engineering graduates. (Elementary economics concepts tell us that the number of engineering jobs is a function of the salary that employers are willing to pay. At $20,000 per year there would be millions of new job opportunities for scientists and engineers. At $100,000 per year, far fewer companies would create employment opportunities. Of course, the number of students interested in those jobs would be inversely influenced.) In response to pressure from universities, NSF took the position that U.S. demographic trends were sure to lead to a shortage of scientists and engineers. At a hearing of the House Science Committee, Congressman Wolpe, Congressman Boehlert, demographers, economists, and numerous representatives of professional societies, including IEEE, refuted the NSF testimony and easily identified flaws in both the reasoning and data of NSF.[30] Despite this, in 1996 at a Senate Republican Conference on National science and technology policy chaired by Senator Frist, some university presidents were still blindly clinging to the out-dated, well-refuted NSF position that the U.S. has a shortage of graduate scientists and engineers.[31] Massy and Goldman have co-authored a study concluding that about 22% of

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[29] Dr. Joseph Bordogna, "Next Generation Engineering: Innovation Through Integration", keynote speech at NSF Innovators' Conference, April 8, 1997, Washington DC.

[30] Washington Post, "Scientist Shortfall a Myth, NSF Study Seriously Flawed, Panel Is Told", April 9, 1992.

[31] Gover was a participant in this conference and was surprised to have concerns about immigration policy developed by IEEE-USA countered by university presidents reciting the discredited NSF argument. Fortunately, members of the Senate in attendance were fully aware that these arguments had been discredited four years previously.

the new doctorates in science and engineering could fail to find suitable employment when the supply-demand system achieves steady state.[32]

Of course, trade associations are feeding the news media distorted stories of shortages of engineers and scientists. In 1997 the Information Technology Association[33] (ITA) announced that 10% of the information technology jobs in the U.S. are vacant because there aren't enough trained people to fill them. ITA's president, Harris Miller, placed part of the blame on the Nation's K-12 schools for not properly interesting children in math and science.[34] Following the ITA study, the Department of Commerce Technology Administration issued a report[35] that did little more than repeat the statistics issued by the ITA and create the impression that the Federal government also believes that a worker shortage exists. The Congressional institution, The Government Accounting Office, conducted a study at the request of Congressmen John Dingell and George Brown and issued a report that cast doubt on the statistics used by the DOC.

> *In a report issued March 23, GAO said the Commerce Department study, America's New Deficit: Information Technology Workers, contains "serious analytical and methodological weaknesses" that undermine the report's conclusions that a severe shortage exists. The report also criticizes the Information Technology Association of America (ITAA) for reports that raised national alarms about a "severe shortage" of computer workers. GAO questioned the reliability of ITAA's survey findings, saying they were not backed by sufficient data.*[36]

What Mr. Miller and others, especially the Department of Commerce, seem to be overlooking is that supply and demand are not independent variables - both are functions of salary. If there is a worker shortage, it is at salaries companies prefer to pay. Increase salaries of scientists, engineers and computer workers or reduce the earning potential of alternative career paths (medicine, law, management, business, finance, etc.) and the shortage will disappear. Richard Estrada reported in a Dallas Morning News editorial,

> *If labor shortage claims are used to circumvent U.S. workers and promote the massive entry of skilled foreign workers willing to work for less, that which is supposed to help America can easily hurt America. In particular, the long-term consequences of promoting dependency on foreign labor rather than training native-born workers could boomerang. ... Two years ago, the Fortune 500 insurance provider, AGI Corp. fired a staff of native-born computer workers and replaced them with newly arrived workers from India. ... the real question is, how deeply committed are Congress, the nation's high-tech employers and higher education to providing America's unskilled workers with the tools to move up the job ladder?*[37]

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32 William F. Massey and Charles A. Goldman, The Production and Utilization of Science and Engineering Doctorates in the United States, research supported by the Alfred P. Sloan Foundation and the RAND Institute for Education and Training.

33 Information Technology Association of America, Help Wanted: The Workforce Gap at the Dawn of a New Century, February, 1997. The conclusions reached in this study were obtained from surveys of large and mid-size IT companies. It estimated that there are 190,000 unfilled IT jobs in the U.S. If the compensation growth trends (annual salary growth between 12% and 19.7%) reported in this study are correct, this employment shortfall will soon be corrected by the free market.

34 Albuquerque Journal, "Study Finds Deficit of High-Tech Workers", March 12, 1997.

35 US Department of Commerce Technology Administration, America's New Deficit: Information Technology Workers, 1997.

36 Chris Brantley, "Senate Committee Hears Industry Complain of Information Technology Worker Shortage," IEEE-USA Legislative Report, April 9, 1998, p. 3.

37 Richard Estrada, The Dallas Morning News, "Retool America's Unskilled Labor", Albuquerque Journal, January 18, 1998, B3.

Although we are emphasizing lack of salary growth serving to inhibit youth from pursuing a career in engineering, as Dr. Mary Good has pointed out, corporate employment practices have not endeared the science and engineering professions to America's youth.

> *To add to the trauma, we have had to endure downsizing and reorganization in many of our American nameplate companies. ... It has particularly affected many of our scientific and technical professionals and changed forever their view of what a career path means. Thus, perhaps it is not surprising that we often hear cynicism and skepticism in the voices of average Americans and that many of our colleagues have not encouraged their children to follow in their footsteps of a science or engineering career.*[38]

In Table IV we have summarized a recent salary history for engineers. What has actually happened is that the financial incentives for a graduate engineering and computer science education have not been sufficient to attract U.S. born citizens to pursue the MS or Ph.D. Contrary to current mythology, this is largely a consequence of salary and the perception that engineering has become a journeyman profession. Salary stagnation, age discrimination, lack of employer loyalty, educational obsolesce, and rapidly changing intellectual demands have made science and engineering careers less attractive than other career options for the native-born "best and brightest".

Table IV: Salary trends for engineers since 1986.[39] All dollars are in 1982 dollars. To convert to 1997 dollars multiply the salary given by 1.67, the consumer price index (CPI) for 1982 measured relative to 1997. To convert to any year's dollars multiply by 1.67 and divide by that year's CPI[40].

Year	CPI	BS Starting Salary	After 10 Years All Degrees	After 25 Years All Degrees	Median Salary All Degree Levels
1986	1.47	$26,171	$39,118	$48,623	$40,083
1987	1.42	$26,484	$39,344	$48,336	$40,463
1988	1.37	$26,188	$38,565	$48,401	$39,801
1989	1.30	$25,186	$37,366	$47,275	$38,315
1990	1.24	$24,570	$36,875	$46,914	$38,008
1991	1.19	$24,666	$36,795	$46,402	$38,242
1992	1.15	$25,000	$36,000	$45,670	$37,626
1993	1.12	$23,864	$35,849	$45,807	$37,596
1994	1.09	$23,790	$36,060	$46,490	$38,582
1995	1.06	$23,426	$35,056	$45,494	$37,641
1996	1.03	$24,403	$36,346	$47,515	$39,187

Elementary economics allows one to easily show that there is a supply curve for engineers and a demand curve for engineers. It is at the intersection of these two curves where the number of engineers that the marketplace can absorb and the salary at which they can be absorbed are identified. In a free market environment, when the supply is less than the marketplace is prepared to absorb at a certain salary level, salaries increase (unless, of course, the supply is artificially increased). The increased salary incentive attracts others to

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[38] Dr. Mary Good, "A Second American Century? Opportunities and Challenges in the 21st Century", C&EN, April 14, 1997, p. 42.

[39] These data were prepared for the IEEE Workforce Committee by Mr. Vin O'Neill, IEEE-USA staff. His source was the Engineering Workforce Commission, Engineers Salaries: Special Industry Reports, 1996.

[40] Nation's Business, March 1997, p. 30. The original source was U.S. Bureau of Labor Statistics. These data assume a CPI increase of 3% in 1997.

become engineers and equilibrium is reached.[41] Rather than allow the domestic supply and demand for engineers to come into equilibrium, U.S. universities at the urging of U.S. companies are adjusting the supply curve by accepting foreign students into their graduate schools and then **using U.S. taxpayer supported Federal R&D grants to pay for their education.** Having paid for their graduate education, policymakers argue that the foreign-born graduates should be permitted to work in the U.S. because they are the best and brightest youth available to fill the jobs. This policy suppresses salaries and makes an engineering graduate education even less attractive to U.S.-born engineers. Thus flawed public policy introduces a positive feedback loop in the system.

Today's supply of Ph.D. candidates in science and engineering has less to do with the labor market for Ph.D.s than it has to do with the production needs of academia, for example, providing low cost teaching and research assistants. Massey and Goldman drew this conclusion after numerous faculty interviews conducted at 210 research and doctoral granting institutions and approximately 1,000 non-doctoral granting institutions. They point out,

> *Too many doctorates are being produced in engineering, math, and some sciences. The long-term structural overproduction, estimated to average about 22%, contradicts dire predictions of long-term shortages. However, the statistics say nothing about short-term imbalances. ... The (long-term employment) gap is largest for mechanical (44%) and electrical engineering (41%). Civil engineering (33%), mathematics (32%), biosciences (28%), and chemical engineering (26%) also show gaps in excess of 25%. ... **Increasing university sponsored research funding would worsen Ph.D. job prospects over the long run.** Immediate gains due to faculty expansion would give way to increased oversupply as expanded doctoral programs begin to produce graduates. The same is true for increases in sub-doctoral enrollment.*[42]

c. Engineers and Immigration. We present in Table V IEEE compiled immigration data. These data are consistent with NSF data which show[43] that 56% of engineering doctorates earned in the U.S. between 1991 and 1995 were to students who received foreign baccalaureate degrees. For mathematics the fraction was 52%, for computer scientists 49%, for physicists 43% and for chemists 37%. Despite an overall decline in immigration to the United States in 1993, the admission of scientists and engineers continued to rise: a 3% increase over 1992 which follows a 62% increase over 1991. At the MS level roughly one-third of the engineering graduates of U.S. research universities are foreign-born and at the B.S. level, less than 10% of the graduates are foreign born. Some state-funded universities have graduate programs in engineering in which over 75% of the students are foreign born.

Some state universities have been able to deceive their state legislatures and governors into believing they are leading research universities and that they must have foreign-born graduate students to support their research that is revolutionizing man's quality of life. But many members of the U.S. Congress are fully cognizant of the deception. Congressman George Brown, one of the staunchest long-term supporters of Federal R&D, made it clear that he understands the linkage between funding for university research and the job market for Ph.D. graduates in science and engineering.

> *This unthinking linkage of R&D to graduate education means that the number of Ph.D.s produced reflects the availability of academic R&D funding, rather than having a relationship to a set of national goals for S&E graduate education. ... The predictable result of this haphazard system is a series of surprises such as the current*

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41 See, for example, Walter J. Wessels, Economics, Barron's Business Review Series, 1993, p. 51 for effects of shifts in supply.

42 William F. Massy, Stanford University, and Charles A. Goldman, RAND, The Production and Utilization of Science and Engineering Doctorates in the United States, report supported by a grant from the Alfred P. Sloan Foundation and the RAND Institute for Education and Training, August, 1995, p ii.

43 National Science Foundation/SRS, Survey of Earned Doctorates for the years 1991-95, http://www.nsf.gov/sbe/srs/nsf96334/foreign.htm.

"overproduction" of S&E Ph.D.s. ... restoring funding for federal R&D will not only not fix the problems in graduate education, but may make them worse. If true, this data indicates that broad S&E graduate education reform is needed before we can discuss levels of funding.

Table V: Flow of foreign born personnel into U.S. engineering and science professions in 1994[44].

Category	Number
Overall Civilian Workforce	123,060,000
Engineers Employed in U.S. Workforce	1,866,000
Computer Scientists Employed in U.S. Workforce	916,000
Natural Scientists Employed in U.S. Workforce	535,000
Permanent Foreign Engineers Admitted	10,793
Permanent Foreign Computer Scientists Admitted	2,781
Permanent Foreign Natural Scientists Admitted	3,104
All Permanent Foreign Admissions	804,416
Temporary Foreign Engineers Admitted	43,778
Temporary Computer Scientists Admitted	12,271
Temporary Natural Scientists Admitted	9,423
All Temporary Admissions	470,781
BS Engineering Degrees Awarded by US Schools	64,946
MS Engineering Degrees Awarded by US Schools	31,943
Ph.D. Engineering Degrees Awarded by US Schools	6,458
BS Engineering Degrees Awarded to Foreign Nationals by US Schools	4,908
MS Engineering Degrees Awarded to Foreign Nationals by U.S. Schools	10,385
Ph.D. Engineering Degrees Awarded to Foreign Nationals by U.S. Schools	3,376

(Much of the material in this section is taken from the research of David North[45], William F. Massy, and Charles Goldman. The work of these diligent public policy researchers was funded by the Alfred P. Sloan Foundation. We are especially grateful to the Alfred P. Sloan Foundation and its president, Dr. Ralph Gomory, for having the wisdom and boldness to address complex and controversial issues such as the impact of immigration policy on the careers of native born engineers and scientists. Of course, agencies lack the courage to address controversial issues with integrity. We also congratulate IEEE-USA for having the boldness to speak out on this issue. Finally, we congratulate the House Science Committee and one of its staff, Edith Holleman, for addressing this issue in hearings and exposing weaknesses in U.S. practices.)

In addition to an oversupply of engineers at salaries comparable to other professional alternatives, we are graduating about twice as many Ph.D.s in physics as there are employment openings. Physicists and engineers, particularly at the Ph.D. level, often compete for the same employment opportunities. Furthermore, one of the major employers of Ph.D. physicists, Federal laboratories, have been downsizing for several years. Unlike much of corporate downsizing, when Federal laboratories downsize the lost jobs do not appear as outsourced jobs.

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44 These data were compiled for the IEEE-USA Workforce Committee by Vin O'Neill, IEEE-USA staff. The first four rows of data on employment trends were provided by the Bureau of Labor Statistics, U.S. Department of Labor. The next eight rows of data on permanent and temporary admissions of foreign engineers and scientists were compiled by David S. North of Arlington, VA. The next six rows of data on engineering degree awards were compiled by the IEEE Engineering Workforce Committee.

45 David S. North, Soothing the Establishment: The Impact of Foreign-Born Scientists and Engineers on America, University Press of America, 1995.

Eldon interprets today's condition to mean that the U.S. has overinvested in a vast infrastructure of university research facilities that have produced most of the world's Nobel prizes, rather than products that can contribute to economic growth, as well as a glut of Ph.D.s in science and engineering. He argues that this overinvestment has been funded at U.S. taxpayer expense and it has produced professors who do research, at public expense, instead of teach. He also points out that another consequence of the current condition is the danger it poses to U.S. security - weapons systems components, software and products necessary for defense increasingly must be purchased from foreign sources where possible adversaries also can obtain them.[46]

The effects of U.S. immigration practices on engineering are listed below. Like most controversial policy issues, there are winners and losers.

♦ **Companies Hire the "Best and Brightest" Graduates.** U.S. companies have access to the best and brightest Ph.D. scientists and engineers in the world at salaries more in line with global competitors than those of other U.S. professionals. Some U.S. companies argue that their continued success in the marketplace depends upon this access.

> *Mr. Maibach (vice president of government affairs for Intel) said 80% of Intel's engineers are foreign-born and U.S. trained. ... We (Intel) need immigration law changes to allow us to hire foreign students trained at taxpayer expense, Mr. Maibach said Wednesday at a forum organized by the Economic Strategy Institute.*[47]

One year later, Intel announced that it planned to lay-off 3,000 workers.

Of course, multinational, global companies already can get engineering less expensively abroad than in the U.S. Therefore, if these companies can't hire U.S. engineers at international rates, they can and will move their engineering off-shore. Japanese companies like Toyota, Honda, and Nisson engineer in Japan the automobiles they manufacture in the U.S. We can increasingly expect companies to move their engineering to those Nations where it can be done most cost-effectively by the highest quality engineers.

♦ **Graduate Schools Have the "Best and Brightest" Students.** U.S. engineering graduate schools have the best and brightest graduate science and engineering student body in the world to support graduate research and teaching at relatively low wages and to keep their graduate education pipeline filled to capacity. This increases the quality of university research and increases the liklihood that U.S. university researchers will win Nobel prizes.

♦ **Graduate Schools Have the "Best and Brightest" Faculty.** Engineering faculty positions are filled from the "best" candidates available in the world, including those born outside of the U.S.

♦ **Native Born Students Are Losing Interest in an MS or Ph.D. in Engineering.** The brightest U.S. engineering and science students, including women and minorities, are increasingly attracted to graduate education and employment options, e.g., MBA, law, investment banking, etc., other than a MS or Ph.D. in science and engineering. There is also a degree trickle down effect. That is, this condition creates the impression that engineering, even at the BS level, is primarily a career option for foreign-born students.

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46 Charles Eldon, Past President, IEEE, personal communication to James Gover.

47 Journal of Commerce, "US chip maker pushing Congress for changes in immigration laws", March 14, 1997.

♦ **Companies Practice Age Discrimination and Need Not Invest in Retraining.** U.S. companies find it is more cost effective to dispose of scientists and engineers than to retrain them for new assignments, particularly when the public is willing to pay for the education of their foreign-born replacements. Thus, U.S. scientists and engineers, both foreign born and U.S. born, often experience age discrimination in the workplace.

♦ **Other Nations: Short-Term Brain Drain, Long-Term Employee Training.** Other nations experience a brain drain over the short term; however, over the long term some countries, e.g., first Japan, then South Korea and Taiwan, have benefited by having their citizens return to their country of birth after gaining several years of valuable work experience in the U.S.

♦ **Taxpayers Are Misled and Confused.** U.S. taxpayers are increasingly puzzled about why their taxes should be spent educating foreign-born college students, particularly when this makes a graduate degree in science and engineering an unattractive career option for their children and grandchildren.

♦ **Diffusion of Military Technology.** When foreign students return to their home country, diffusion paths are created for transferring knowledge off-shore, including knowledge that can be used for military purposes.

d. Policy Options

Extend Working Life of Engineers and Scientists. The politically easiest, lowest cost, and most timely solution to temporary engineering employment shortages would be to initiate a National retraining program for scientists and engineers that would extend their working life to age 70. This solution also advantages the U.S. Social Security system. Obviously, an analysis of these and other alternatives needs to be made to see which is likely to produce the highest **public outcome at the minimum public cost.** It should be pointed out that while government fiddles with Social Security assumptions, debates taxing Social Security income, considers means testing, and recommends investing Social Security funds in stocks, Peter Drucker has a different picture of the root cause of the Social Security problem.

> *The retirement age in all developed countries will have to go up to 75. Most people who reach 65 are perfectly capable of functioning. All present talk of financing Social Security is beside the point. The point is not money. The point is production.*[48]

Of course, an increase in the retirement age would have to be accompanied by enforcement of age discrimination laws. IEEE reports that member opinion surveys reveal that 11 to 12 percent of IEEE members claim that they have been asked to retire early and 19 percent report that they have experienced age discrimination in their place of employment. It should be noted that these surveys include engineers in their 20s, 30s, 40s, and 50s that are not yet eligible for retirement, so the fraction of 60 year old engineers being pressured to retire may be in the 30 - 50 percent range. IEEE data also show that an unemployed engineers' ability to gain new employment is inversely proportional to their age with their jobless period increasing by two weeks for every year of age.[49] It is peculiar that many members of the U.S. Senate that are well into their seventies are ably serving their constituents and Senator John Glen at age 77 is ready, able and willing to fly a shuttle mission, while engineers over 20 years younger are being pushed out of the job market and urged to retire early.

Restrict Federal Funds for University Research. Massy and Goldman report,

> *A few years ago, one of us participated in an Office of Technology Assessment advisory panel whose charge was to assess the health of U.S. academic research.*

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[48] Lenzner and Johnson, "Seeing Things as They Really Are", Forbes, March 10, 1997, p. 126.

[49] Memorandum from Christopher Currie, IEEE External Communications Coordinator, to James Gover, subject: Age Discrimination and Engineering, August 11, 1997.

Not surprisingly, conversation at one of the meetings lamented the "underemployment" of young scientists and engineers - the difficulty of establishing oneself in a suitable post and developing an independent research career. A distinguished scientist in the panel suggested that Congress should appropriate sufficient additional research funds to provide America's doctorate-holders the chance to pursue effectively the careers for which they are trained. The argument was couched in terms of the national interest as well as on humanistic grounds, since, with underemployment, a portion of the investment in doctoral training is wasted. That argument just didn't seem right. While expanding sponsored research budgets undoubtedly increases the demand for doctorates, one suspects there may be supply-side effects as well. Why should we believe that the demand effects outweigh the supply effects over the long run, after doctorate production has had a chance to adjust? Could it be that, while salutary at the beginning, increased research funding actually makes doctorate underemployment worse over the long run?[50]

One could restrict the fraction of federal research funds that can be spent on salaries for non-U.S. citizens or further restrict the issuance of work visas to those graduating from U.S. universities. Alternatively, the public's contribution to the cost of educating foreign-born graduate students could be compensated by their U.S. employers. Of course, the problem could be addressed by further limiting the flow of federal research funds to universities.

The Department of Labor has attempted to discourage government bodies and universities funded by Federal R&D from hiring foreign-born post-docs over U.S. citizens by stipulating such employees must be paid at the highest prevailing wages in the community. To employ a foreign national in H-1B status, a university must establish (1) that the position involves a specialized body of knowledge requiring the minimum of a bachelor's degree and that the foreign national has the required degree in the field in which she or he is employed; (2) that the person will be employed initially on a temporary basis - even if the position is permanent; and (3) that the employment of this person will not adversely affect the employment of US workers as evidenced by paying the higher of the actual or prevailing wage for a position. As is often the case with regulations, this regulation has had an unintended consequence. Because U.S. citizens are often not interested in these positions (due to limited opportunity for economic rewards in comparison to other professional alternatives, lack of qualified applicants, etc.), the only choice may be foreign citizens. The allure for the high pay (by foreign standards) demanded by law has served as an incentive for outstanding non-U.S. students to pursue U.S. careers in engineering and science and because the pay remains low (by U.S. standards in comparison to other professional opportunities) this regulation has not made this career option any more attractive to U.S. citizens.

Further Restrictions on Immigration. Fechter and Teitelbaum have made the following recommendation,

We recommend that a balanced panel of distinguished experts be created to propose separate immigration ceilings for scientists and engineers. The panel should operate under the aegis of the Office of Science and Technology Policy, with input from the Department of Labor, the INS, and Federal science and technology agencies such as NSF, the National Institutes of Health, and the National Aeronautics and Space Administration. Its recommendations would be considered and administered by the Department of Labor and the INS as part of the larger numerical limits set by congressional legislation. ... The panel should base its recommendations on a comprehensive review of recent immigration ceilings; how they affect the health of our

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[50]William F. Massy, Stanford University, and Charles A. Goldman, RAND, The Production and Utilization of Science and Engineering Doctorates in the United States, report supported by a grant from the Alfred P. Sloan Foundation and the RAND Institute for Education and Training, August, 1995, p 1-1.

National R&D enterprise; and whether they are consistent with explicitly stated objectives, including the relative attractiveness of careers in science and engineering.[51]

Compromise. Eldon[52] argues for a compromise among a variety of policy options that both attracts the best and brightest engineers in the world to the U.S., but encourages them to become U.S. citizens. There is currently little incentive for foreign students from industrialized countries to stay in the U.S. To the contrary, there's increasing incentive for foreign-born graduates to return home where they have high value not only because of their education and work experience in the U.S., but because they have learned much about the culture of the people who own the largest economy in the world. The following are actions that Eldon offers to ameliorate this problem:

- Foreign-born engineering and science students should pay for the full cost of their U.S. education or perhaps even more to cover the cost of hidden public subsidies to universities. For engineering, that would be far in excess of normal out-of-state graduate school tuition.

- Foreign students should not be eligible for teaching assistant or research assistant jobs or financial aid unless they "commit" in some way to work in the US for at least the number of years that they spend in US schools (just like students at West Point, Annapolis, and the Air Force Academy commit to "service" in the military). Some nations, e.g., Singapore, require that kind of commitment from students that attend their universities.

- "Re-education" of scientists and engineers should be subsidized only for U.S. citizens, thus further encouraging foreign graduates to become U.S. citizens.

B. Research University Costs.
a. Introduction. The major public concern about research university education is its cost. The Economist recently reported,

> *A recent report from the Council for Aid to Education, a subsidiary of the RAND organization in Santa Monica, reckons that their (universities) real cost doubled between 1976 and 1995, and gives warning that if they were to double again in the next 20 years, some 7m students would be priced out, with disastrous social implications.*[53]

Lack of productivity growth, in combination with stagnation or reduction in income have resulted in education costs that an increasing fraction of America's population can no longer afford. Just as the shifting of wealth has made a college education a near necessity for personal income growth, the cost of college has made college less accessible to those in the low and middle income groups. The June, 1997, graduating undergraduate class of 1.2 million spent, on average, $150,000 of private and government funds for their education.[54] Of course, funds provided to public colleges and universities by taxpayers create the illusion that public schools cost less than private schools. Most analyses indicate that private schools actually cost less when the tax bite is included in the calculus.

The average debt for those graduating from college is $11,000 with some carrying debts of $30,000 to $40,000.[55] During the 1980s health care prices grew 117%; the price of attending

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[51] Alan Fechter and Michael S. Teitelbaum, "A Fresh Approach to Immigration", Issues in Science and Technology, Spring, 1997, pp. 31-32.
[52] Charles Eldon, Past President, IEEE, personal communication to James Gover.
[53] The Economist, "The Knowledge Factory", October 4, 1997, p. 11.
[54] USA Today, "College Costs Too Much, Fails Kids", July 17, 1997, p.15A.
[55] The Washington Post National Weekly Edition, "You've Made the Grades, Now It's Payback Time", July 8-14, 1996, p. 20.

public and private colleges increased 109% and 146% respectively.[56] In 1996 the price of tuition at state-assisted colleges and universities averaged 8.9% of annual family income in comparison to 4.5% in 1980. Of course, these figures do not include the subsidy paid through state taxes, the federal subsidies, funds drawn from endowments, and the many contributions made to universities by alumni and others. In 14 states the cost of tuition at a state-assisted college exceeds 10% of annual family income in that state. A Washington Post poll showed that 58% of Americans believe that a good college education is becoming too expensive.[57]

b. Cost Research. In June of 1997 Congress created an 11 member National Commission on the Cost of Higher Education, composed primarily of college educators, and tasked it to design strategies to limit increases in tuition and other college costs. This group has not yet brought any new recommendations to Congress on how costs might be controlled; instead, it angered several members of Congress by defending cost growth.[58] We site this failure, not to criticize the Commission, rather, we wish to illustrate that part-time commissions are not the best way to conduct complex, multi-dimensional systems studies. Congress can be guaranteed that the traditional political process of polling experts and synthesizing their opinions into a set of recommended policies will not solve the college cost problem.

Charles Clotfelter has done an analysis of cost escalation at Harvard, Duke, Chicago, and Carleton College, all elite institutions of higher learning.[59] Harvard's annual tuition, room, and board expenses passed $10,000 in 1982, $20,000 in 1991, and are expected to exceed $30,000 in 1998. During the 1980s, after adjusting for inflation, the average annual rates of spending growth and tuition growth were 6.8% at Duke, 5.3% at Harvard, 6.0% at Chicago, and 5.7% at Carleton. Clotfelter has attempted to ascribe portions of the spending growth to changes in market prices of labor and materials, growth in numbers of faculty and staff, increased fringe benefits, growth in financial aid, and increased administrative spending. After making these allocations, he finds that 38% of the cost growth at Duke, 64% of the cost growth at Harvard, 40% of the cost growth at Chicago and 56% of the cost growth at Carleton are unexplained by these factors. He proposes that the unexplained cost growth is due to increased quality of service, new activities, and increased internal funding of research. Clotfelter found that information technology may have increased the quality of college education, but has not led to cost reduction. He discovered that over a fifteen year period there has been substantial reductions in faculty teaching time with the freed-up class time devoted to increased research. Competition among elite institutions for prestigious faculty members has led them to lower teaching loads and maximize the time and opportunity for research.

Breneman's analysis[60] of Clotfelter's research led him to conclude that teaching loads have fallen at elite universities, administration costs have increased, average class size for undergraduates is large and rising, much undergraduate teaching is done by graduate students or other irregular faculty, research takes precedence over teaching, and graduate education is supported on the backs of undergraduates who pay for it through large classes, inflated tuition, and limited access to senior faculty. Thus, graduate schools have shifted much of the cost growth of graduate education, 50% of which is for foreign students, to undergraduate education. A recent study by the Carnegie Foundation entitled Reinventing Undergraduate Education: A Blueprint for America's Research Universities, made the following observations:

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[56] George Will, "Education Today: Pay More, Learn Less", The Washington Post, March 24, 1996.

[57] The Washington Post National Weekly Edition, "What About Us?", September 23-29, 1996, p. 9.

[58] Congressional Quarterly, "Commission on College Costs Back to the Drawing Board", December 20, 1997, p. 3129.

[59] Charles T. Clotfelter, Buying the Best: Cost Escalation in Elite Higher Education, Princeton University Press, 1996.

[60] David W. Breneman, "Unbounded Aspirations: why college costs so much", Harvard Magazine, Sept.-Oct., 1996, pp 26-30.

Undergraduate students, particularly freshmen, are being shortchanged by US research universities .... undergraduate students are often taught by graduate students, not teachers, and many are graduated without a coherent body of knowledge.[61]

Baccalaureate students are the second-class citizens who are allowed to pay taxes but are barred from voting, the guests at the banquet who pay their share of the tab but are given leftovers. ... The universities mentioned as emphasizing graduate education and research over undergraduate studies include Harvard University, the Massachusetts Institute of Technology, the University of Alabama at Birmingham and Kent State University. The 125 research institutions in this country make up only 3% of the institutions of higher learning, yet they award nearly a third of the bachelor's degrees.[62]

Dr. Allan Bromley has pointed out that the more Federal research funds a university receives, the more internal funds it must pull from tuition or other internal sources to support the research.

the typical private research university finds that for every dollar of Federal grant and contract money that it receives, even when the government provides the full amount of the allowed overhead funding, something between thirty-five and forty cents remains unreimbursed. The only source for this unreimbursed fraction of the cost is interest on the university endowment, gifts from individuals and foundations, and tuition; but these three sources are badly needed to cover areas of activity in the universities which do not have access to Federal funding and, moreover, tuition cannot continue to rise as it has in the past at three times the average growth rate of the average family income.[63]

Erik Larson has examined cost growth at the University of Pennsylvania. He reports that colleges went on a building and hiring binge following the Soviet Union's launch of Sputnik in the 1950s. New faculty salaries were largely covered by Federal grants. This period was followed by a surge of Great Society financial aid money in the mid 1960s. **Until 1982 tuition charges at private colleges tracked the consumer price index (CPI). However, since then college tuition at private colleges has increased two to four times as fast as the CPI.** Larson notes that recent cost growth has been driven by the Chivas Regal effect - tuition was raised as much as the market would bear and the public was conned into believing that the higher the cost of the college, the better the education. He explains that conspiracy among those colleges that make up a large fraction of the tier 1 mega research oligopoly also contributed to cost growth.

For years a group of America's most influential schools traded data on tuition policies. Penn, Harvard, M.I.T., Princeton, Brown, Columbia, Cornell, Dartmouth and Yale shared information about future tuition rates and fees, agreed never to grant aid solely on the basis of a student's academic merit, and met to negotiate how much need-based financial aid should be offered to individual students accepted by two or more of the member institutions. ... By liberating schools from price competition, the arrangement may have allowed them to boost tuitions to artificially high levels and, thanks to imitation by others, drive up tuition throughout the country.

After a two year anti-trust investigation by the Department of Justice, these schools abandoned their explicit conspiracy to fix prices. Larson reports that universities have not utilized their endowments to reduce the cost of tuition and have typically annually spent less

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[61] CNN U.S. News, "Report: Undergraduate Education Is Lacking,' April 20, 1998.

[62] USA Today, "Report: Big Schools Neglect Undergrads", April 20, 1998.

[63] D. Allan Bromley, "The Future of the Research University", presentation to the Annual Meeting of the American Society for Engineering Education, February 23, 1997.

than 3% of their endowment. He argues that if Harvard with its $9 billion endowment were to increase endowment spending by 1 percent, it could cut its base undergraduate tuition costs in half.[64]

c. Impact of Regulation on Research University Costs. The Nation's 3,600 colleges and universities are regulated by 65 accrediting associations, 49 state regulatory agencies, and the U.S. Department of Education. Because of these regulatory groups, the barriers to entry of a private entity in the education business are formidable. Regional accreditation associations must be recognized by the Secretary of Education in order for the students at the universities they accredit to be eligible for Federally funded financial aid programs. Most accreditation associations require that faculty control their curriculum and instruction and play a major role in business matters including approval of their institution's budget. The entire accreditation process can easily take between 4 and 6 years after a new institution opens its doors for students. Additional regulations are imposed by both the Federal government and by state governments.[65]

While regulations protect the oligopoly status of universities, they also increase the cost of research. These regulatory burdens place stress on the research infrastructure and inhibit both the quality and quantity of university research. In many instances, regulations are directed at social goals unrelated to the conduct of research and are implemented in a conflicting, overlapping and overly prescriptive manner. The result is that the regulations often do not achieve their intended goals, build cynicism among the community of academic scientists, and add unnecessarily to the indirect costs of research.

In 1992 the Council on Governmental Relations (COGR)[66] responded to Mr. C. Boyden Gray, counsel to President Bush, in response to his moratorium on new regulations which directly affect 135 large research universities. Among other stinging criticisms, COGR responded,

> *Ill-defined and misapplied regulations are having a detrimental effect on the productivity, costs, and results of university research efforts and are not in the best interest of the nation.*

COGR recommended five actions, one of which pointed out that one time certifications of a university to a single representative Federal agency should be sufficient to assure compliance with each of 50 different Federal regulations. [The normal requirements are that every proposal submitted on behalf of a university, typically between 2,000 and 6,000 per university per year, require a signed form stating that the regulation is being met.] It noted,

> *A great amount of effort is wasted on numerous certifications now required by several Federal agencies either on each award or on a proposal by proposal basis. This includes certification relative to civil rights, employment of the handicapped, Equal Employment Opportunity, lobbying, procurement integrity, debarment and suspension, drug abuse prevention certificates, non-delivery of federal debt, etc.*

COGR, for example, noted,

> *One distressing example of micromanagement is the recent revision of the NIH application forms for research and training grants. According to the agency's own estimate, the estimated time for completing the new forms has increased from 10-15 hours to 50 hours. It is important to note that this estimate does not cover the preparation time of the scientific part of the proposal but reflects the increasing demand for administrative detail. In 1991, the National Institutes of Health received 38,271*

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[64] Erik Larson, "Why Colleges Cost Too Much", Time, March 17, 1997, pp. 46-55.

[65] Lehman Brothers, Second Annual Education Industry Conference, February 11, 1997, pp. 121-125.

[66] Milton Goldberg, President of COGR, "The Regulatory Environment for University Science", April 24, 1992.

applications for competing awards. This figure will double when the material required for non-competing awards is added. Given this volume, the increased man-hours and costs for completing the form are staggering. This diversion of resources from science to administration does nothing to increase scientific productivity.

In a 1996 letter to Representatives Dan Miller and John Porter,[67] the GAO pointed out that in 1995 NIH distributed over $8.8 billion to NIH's Extramural programs supporting biomedical research at 1700 organizations, mostly colleges and universities. The report listed 68 Federal regulations which required regulatory compliance for NIH grantees and it said, "some officials told us that states and localities impose their own regulations that are more stringent than Federal regulations in some instances."

A member of the COGR advisory board[68] and a director of a university office of sponsored programs and research told us that "Federal regulatory requirements have accelerated in the last ten years with at least 26 new regulations added to proposals." Among the certification documents is a ridiculous requirement that makes a university official liable for insuring that payments will not be made to individuals involved in campus unrest. There are approximately 67 others, some equally absurd.

The state of Illinois has invested in technology that links students regardless of location or age to universities, community colleges, plants, factories, and companies. Students in rural areas have access to the Illinois Math and Science Academy where instructors download lessons onto the Internet so that teachers in other parts of the state can access them. Illinois is doing this because they have come to realize that they can no longer expect people to always find their way back to the university or community college. However, because of regulations, Illinois K-12 science students still do not have access to the best teachers.

Society needs to destroy the barrier that prevents everyone who is not certified by teacher unions and state governments or who does not have credentials to teach from educating people. Leon Lederman, a Nobel Prize-winning scientist in Illinois likes to teach young people. ... He knows that if he does not reach them early enough - when they are juniors or seniors in high school - he may lose them. But Lederman cannot teach in Illinois high schools. So students must wait one or two more years before they can benefit from his courses in physics at the Illinois Institute of Technology.[69]

C. Tenure Limits.

Some universities are attempting to cope with cost escalation by taking steps to limit tenure. Almost 60% of U.S. college and university faculty are tenured. The intent of tenure is to protect the scholarly work of professors from political pressure and permit them to explore problems and issues without fear of reprisal from university administrators that are puppets of the political system. Today, there are relatively few cases in engineering and the physical sciences where scholarly work is threatened for political reasons, if only because most of it is either unnoticed or not understood by the political system. The biological sciences and other disciplines related to the origin of mankind, the age of the earth, individual freedom, the beginning of life, human sexuality, and morality are exceptions.

The University of Minnesota, in particular, has become a central figure in the tenure debate between university administrators and faculty as its Board of Regents seeks more flexibility in

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[67] Sarah F. Jaggar, Director of Health Financing and Public Health Issues, U.S. General Accounting Office, March 25, 1996.

[68] Private communications with Ardis Savory, Associate Vice Provost for Reseach, University of South Carolina, by Paul Huray, May 9, 1997.

[69] Robert Kustra, "Toppling the Ivory Tower", Across the Board, Extracts from recent reports and conferences of The Conference Board, February, 1997.

tenure-related decisions.[70] From our perspective, while tenure serves many useful purposes, it has two highly unacceptable features:

- In the public's eye, tenure appears to be a license for professors to stop working while continuing to be paid. Nothing could be farther from the truth - college professors, with few exceptions, work very hard and do not exploit the privileges of tenure. Nevertheless, tenure contributes to this public image. The political cost of tenure may well exceed its overall value.

- The measure on which universities rely the most heavily in selecting professors for tenure is number of publications, an output measure, not an ***outcome*** measure. It is well known that metrics shape behavior. Thus, during the formative stage of their career as an educator, the quest for tenure forces professors to become immersed in a value system that, at best, weakly addresses the outcomes those they serve are seeking. There are even instances where the pressure of tenure demands that tenure-track educators make public, through publications, discoveries that have great potential for being patented and growing into a major revenue stream for the university. Tenure shapes behaviors that may not be in the long-term public interest.

If the public is to continue to own universities as it does today, these universities will continue to be influenced by political conditions in the state. If faculty are to be insulated from these pressures, tenure must be continued. However, we do recommend that the granting of tenure be determined less by journal publications and more by teaching success and quality and impact of research on the public. Of course, if public universities grant tenure to faculty, private universities must also do so in order to be competitive in faculty employment. If the entire university system were privatized, there would be no need for tenure.

D. The Balance Between Teaching and Research.

While most research universities see research and teaching as complementary activities, some critics argue that research by professors undermines the quality and effectiveness of their teaching. Critics argue that because only one can have priority, the other must suffer, and the other is usually teaching.

> *Much academic research is dross, churned out merely to advance an academic's career. Worse, the publish or perish syndrome which dominates academia has devalued the original purpose of higher education-that is, education itself. At too many institutions, including many of the most famous, teaching is an after-thought and done poorly. The pursuit of research has gone too far. It is time to tilt the balance back towards education.*[71]

> *You're smart people and so you figured out many years ago that most of your courses were entirely irrelevant information. ... What you learned wasn't how-to-learn, but to recite, to get by, to work the system. School is to learning what "Cliff's Notes" is to literature. You learned to lip-sync knowledge. ... look at what the university is doing to your professors. Wonderful, bright, good-natured people are attracted to teaching at a university ... and then dissuaded from doing what attracted them to the job. No, the classroom is ultimately a distraction, an intrusion on research. ... A university was once thought of as a place for free-thinkers. Not now. The thinking is never free; it is both expensive and shackled. In the absence of free thinking, college has become vo-tech for bureaucrats. A diploma proves that you are already a card-carrying bureaucrat, that you are willing to do what you are told for years at a time. Thus, you are qualified to work for major corporations.*[72]

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[70] Rene Sanchez, "On the Front Lines in the War Over Academic Freedom", The Washington Post National Weekly Edition, November 18-24, 1996.

[71] The Economist, "Teaching Spires", August 24, 1996, p. 14.

[72] Dale Dauten in graduation speech, "Conformity Class Is Over", Albuquerque Journal, May 7, 1997, p. D8.

Regardless of the "right answer" to this debate, this issue and others, especially the tenure debate and the cost issue, have caused the academic community to slowly lose the respect it enjoyed in our society twenty five years ago. The expression "only of academic interest", is often used by even the well-educated as a euphemism for irrelevance that suggests work done by university researchers has little practical value. Universities must take whatever steps are necessary to modify this perception.

The Oak Ridge Associated Universities (ORAU) Science and Technology Policy Committee addressed this polarized debate by polling over 200 faculty and administrators at ORAU research institutions to observe how university professors frame the research versus teaching issue in their own words. A six person study group consolidated their open-ended responses and grouped them into three themes:

- **Research is learning.** It serves to motivate both students and teachers to further their learning and it aids students in developing disciplined mental habits. Research is also aided by the teaching experience and the interchange between students and faculty. The researcher is herself a learner of new knowledge. What better role model for a student than an advanced learner at the frontier of knowledge?

- **Research excites students** and helps them select a graduate school or make a career choice. It is not possible to teach **about** the excitement of science; one must experience that excitement to learn what it means.

- **Research expands teaching** by adding an immediacy and reality to teaching that would otherwise not be present. The intellectual rigor of research carries over into the classroom. The research student is completely aware of the reason for learning and sees the need for both depth and breadth in understanding complex phenomena.[73]

We agree with the position of ORAU. We believe that this debate is a red herring based on the tacit assumption that all colleges and universities should have the same balance between research and education.

The content of classes and education styles of universities are significantly influenced by the educational background and intellectual capacity of high school graduates that attend them. The best universities work very hard to attract students that graduate near the top of their high school classes. The top students from the most advanced high schools in the Nation, including the private prep schools, often make up the dominant fraction of the freshman class in the highest rated universities. But many outstanding students (e.g., Bill Gates, Michael Dell, etc.) become bored with the low level of remedial work offered to the "average" university student and choose to get on with their career without graduating from college.

As The Economist recently noted, U.S. universities have come to be regarded as the best in the world.

> *The United States has moved farther than most countries towards a system of mass higher education and yet its 50 or so great research universities probably achieve higher academic standards than ever before. Their ability to pluck the very best students from an ever-deepening pool of eligible applicants has raised standards, not lowered them. ... The country's best universities are at the apex of a remarkably diverse range of higher education institutions, the rest of which are able to give run-of-the-mill students a university experience that is both more fitting to their aptitude and can be provided at a lower cost.*[74]

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[73] F. Avignone, F. Hilenski, A. Horton, P. Huray, F. Lewandowski, and F. Medway, Teaching and/or Research, Oak Ridge Associated Universities, January, 1993.

[74] The Economist, "The Knowledge Factory", October 4, 1997, p. 4.

While some universities are criticized for an excessive emphasis on research and inattention to teaching, many students that attend the best schools already have strong learning skills and many have demonstrated a capacity to conduct independent study. Consequently, many undergraduate students are ready to be exposed to the excitement of original research, an attitude of excellence in seeking new knowledge, and the opportunity to work with a scholar who is also a learner. Students that attend the highest rated research universities also benefit from the prestige and employment opportunities that accompany graduating from these schools.

Most undergraduate schools attract a distribution of students representing a wider cross-section of capabilities. While the majority of students attending research universities are intellectually prepared for the university experience, many are not. This means that colleges and universities that intend to serve the average high school graduate must begin their curricula by emphasizing 'learning how to learn' and not compromise it by focusing too early on original research. But because these universities desire to advance their perceived status, they imitate practices of the top research universities rather than differentiate their learning services. The **public outcome** of this imitation is not in the best interest of the nation because a large segment of under-prepared students subsequently develop cynical attitudes toward an academic community which does not appear to serve their learning needs.

The better prepared students are for the college experience, the more advanced and independent the learning program universities may offer. Thus, K-12 education is a primary determinant for U.S. university curricula. For an analysis of K-12 education, we refer the reader to the appendix.

E. Public and Private Research Universities: Unfair Competition.

By getting into the education business, operating universities, and selectively subsidizing the cost of attending these universities through lower-fee, in-state tuition, state governments have imposed severe economic handicaps on those private colleges and universities that were attempting to provide quality education while managing and controlling costs. In another study of Federal laboratories we were able to articulate certain circumstances where the public is advantaged by owning the institution that performs its R&D. However, we are unable to identify how the public is advantaged by owning and operating the institutions that provide its research education. In fact, public ownership subjects universities and colleges to a wide array of political pressures that tend to reduce the quality of their education. It is far better to let market forces rather than politicians shape universities.

Major state universities are in direct competition with tier 1 private research universities for both students and research funds. However, since many of the research funds are provided by states, publicly-owned universities have an advantage over private research universities in seeking these funds.

In addition, publicly-owned regional universities and community colleges are in direct competition with private liberal arts colleges, particularly those affiliated with religious groups. Under the stress of this competition, private colleges have either accepted that they must "dumb down" their education process and accept those students unable to compete at regional universities or they have sought to develop high quality education niches. It is difficult for the public to determine which route a particular college has taken.

Cumberland College, a liberal arts college in southeastern Kentucky affiliated with the Baptist Church, has survived competition from subsidized education by developing an education niche that differentiated it from publicly-funded colleges in the region. To overcome State of Kentucky subsidies for public education, Cumberland eliminated vocational programs such as Nursing, specialty business programs, and other programs which were in direct competition with state funded education programs. Cumberland also raised its entrance requirements and eliminated all remedial classes and programs. During this readjustment phase, enrollment declined over 25% from over 2000 in 1989 to less than 1500 in 1995. By the fall of 1997

Cumberland's enrollment had increased to near 1700 and it is anticipated to increase to near 1800 by the year 2000.

Over the past four years, two of three Cumberland graduates have enrolled in graduate or professional programs at other schools. Cumberland competes with "mall-based", state-owned institutions which promote "certification" as an education outcome. To make the changes required to survive competition from publicly funded colleges, Cumberland had to engage in strategic planning and make hard, high-risk decisions that had their future hanging in the balance.[75] Other private colleges which face circumstances similar to those faced by Cumberland and are unable or unwilling to make changes may have missed their opportunity to be distinctive. Without their unique niche, these private colleges are forced to compete with the "Walmart" concept of higher education in which they compete with publicly subsidized schools for the same students in the same programs but without the financial benefit of the public subsidy.

V. Reform of Research Universities

A. Education Models.

Marshall suggests that the old model of education, the Newtonian model, has outlived its utility and must be replaced with new educational models that recognize learning as a property of a complex, adaptive system.

> *By design, we constructed and operated our Newtonian schools as we understood our world, and this produced iatrogenic and learning-disabled institutions that have suppressed reflective thought, creativity, and the innate and inexhaustible human capacity for lifelong growth. ... We must transform the mechanistic paradigm of schooling into an integrated, holistic, and systemic vision of a sustainable learning community.*[76]

We are living in wrenching times with one foot in the past characterized by hierarchies and bureaucracies, and one in the future characterized by teaming and collaboration. Because we're in an evolutionary period of change, old types of organizations, e.g., educational institutions, are not disappearing, but instead becoming smaller parts of an adapting organizational structure. The new organization consists of small internal units that have buying customers. Hewlett Packard, for example, consists of numerous small independent business units each performing a niche function. The HP structure showcases the advantages of self governing teams (small, entrepreneurial, adaptive), in contrast to the weaknesses of hierarchies exemplified by the current university system where decision-making is often paralyzed. Higher education is on the edge of a revolution as distance learning begins what is expected to be a period of sharp growth. The inefficient bureaucracies at some of the more forward looking universities are slowly being replaced by self generating departments that allocate resources in proportion to value gained. The inefficiencies of having a $100K professor teach 5 or fewer students can no longer be tolerated.[77]

Pelton has made the following observation,

> *It is now nearly 2,500 years since the age of Socrates, Plato, and Aristotle. Since that time we have created rocket ships, biotechnology, genetic engineering, lasers, radio astronomy, nonlinear math, chaos theory, satellites, supercomputers, talk-show television, and artificial intelligence. ... Two and a half millennia later, we are still putting*

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[75] Joseph Early, Cumberland College Provost, personal communication to James Gover.

[76] Stephanie Pace Marshall, "Creating Sustainable Learning Communities for the Twenty-First Century", in The Organization of the Future, edited by Frances Hesselbein, Marshall Goldsmith, and Richard Beckhard, The Drucker Foundation, 1997, pp. 177-188.

[77] Robert Floran, Sandia National Laboratories, personal communication to James Gover, summary of observations made at World Futures Society Meeting, July, 1997.

students in a classroom with an authority figure who lectures for prescribed periods of time. We have progressed very little from the educational paradigm used by Socrates and his followers.[78]

Peter Drucker argues that the cost growth in university education will result in major changes in the way education is delivered. He notes,

Thirty years from now the big university campuses will be relics. Universities won't survive. It's as large a change as when we first got the printed book. ... uncontrollable expenditures, without any visible improvement in either the content or the quality of education, means that the system is rapidly becoming untenable. Higher education is in deep crisis. Already we are beginning to deliver more lectures and classes off campus via satellite or two-way video at a fraction of the cost. The college won't survive as a residential institution. Today's buildings are hopelessly unsuited and totally unneeded. ... High school graduates should work for at least five years before going on to college. Then it will be more than a prolongation of adolescence.[79]

Outside of the U.S. the emerging model of education is the distributed megauniversity. These institutions rely on distance teaching methods to reach hundreds of thousands of students. Around the world eleven megauniversities annually teach up to 500,000 students each (Anadolu University in Turkey has 578,000 students and China TV University has 530,000 students.) while maintaining per student education costs ranging between 5 percent and 50 percent of the costs of universities that employ traditional methods.[80]

B. Continuing Education.

The ability of the U.S. to continue to attract high-value-added industries from around the world depends upon having a high quality workforce. Except for some progressive engineering schools, e.g., the University of Cincinnati pioneered cooperative engineering education, the U.S. education system has been designed to accommodate the linear model of learning - during early years one studies then eventually receives a diploma or degree which certifies the state of learning reached. The ability of the educational institution to provide this learning experience has itself been certified by an accreditation board. After "getting the degree", the graduate then marches off to the learning application phase. A consequence of this model is students motivated to "get a degree" as if that were of significance. During a time when the rapid growth in knowledge quickly makes many degrees irrelevant, the concept of a degree seems to be out of step with reality.

In many fields, engineering in particular, learning must be a cradle-to-grave experience and it must be thoroughly integrated throughout the work experience. However, educational institutions are organized to provide courses according to this linear model with the delivery schedule drawn out over a several month period. Our research university system has ignored what is quickly becoming the most important role of education, the continuing education of the workforce. The National Academy of Science observed,

The United States has one of the most diversified, but poorly coordinated training enterprises in the world. ... Work-related training and continuing education are provided by a broad spectrum of private and public institutions. ... Across this vast and diverse training enterprise, there are few common standards, the quality of training is uneven, and important subsets of the nation's current and potential workforce are poorly

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[78] Joseph N. Pelton, Cyberlearning vs. the University: An Irresistible Force Meets an Immovable Object', IEEE Engineering Mangement Review, Fall, 1997, p. 110.

[79] Robert Lenzner and Stephen Johnson, "Seeing things as they really are", Forbes, March 10, 1997, pp. 122-128.

[80] Science, "Schools Ponder New Global Landscape", July 18, 1997, p. 311.

served, particularly with regard to job-related training and continuing education within industry.[81]

Because of the short half-life of engineers' education, continuing education for engineers has been particularly difficult to accommodate. The Competitiveness Policy Council pointed out that the mobility of engineers means that their professional education has become a ***public good*** which individual companies are increasingly unwilling to finance.[82]

Many states, however, have recognized the need to continuously re-certify professional engineers and have recently begun to require annual continuing education units for the maintenance of engineers' certification. To date 3 of the 50 states have passed these regulations. Companies will likely respond by outsourcing the continuing education of their engineers to private or public organizations. An entrepreneurial group of educators has sensed growing opportunity for new sources of income.

C. Corporate Competition.

We note the recent interest shown by investors in the business opportunities presented by the $668 billion annual market for education. Such interest is bound to result in private competition for all sectors of education and especially for those opportunities which are being ignored by colleges and universities (such as continuing education). The competition from outside the traditional education community is likely to self correct accelerating costs and might well initiate intercollegiate competition for students based on costs.

Most universities have been slow to recognize the educational needs of industry and they have acted in predictable, self-serving ways to make modest change in their traditional lecture formats. Although many universities espouse new delivery mechanisms, those mechanisms are mostly intended for geographically local delivery to their historical clients. Most public universities are behaving as if there is no competition from either industry or other colleges and universities, they are largely ignoring the continuous development needs of their own graduates, and they cannot see the wisdom of working together. This is a prescription for a meltdown of the traditional university educational system, perhaps relegating universities to a future of only providing safe houses for maturing teenagers, and as ivory towers of arcane knowledge.

The vacuum in leadership that exists within the current university structure and universities resistance to change has greatly accelerated a trend in recent years toward company-owned universities; there are now over 1,000 of these in the US with two-thirds having been accredited. These, along with distance learning centers represent new competitors for the traditional university. The continued rapid growth of this phenomenon attests to the failure of the current education system to provide the private sector with graduates who can function and add value in the corporate world. We can see these trends occurring all over the United States, where the traditional large, bureaucratic university continues to be plagued by declining enrollment, while the smaller, agile and more responsive technical vocational institutes struggles to keep up with growth, as it attempts to serve the rapidly growing needs of local employers.

D. Technology and The Virtual University.

Distance learning and other technologies will help "reform" universities into more learning- and cost-effective entities, likely in the configuration of multiple, interconnected - in a virtual and real sense - modules of a modest size that will make up the emerging virtual university complex.

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[81] National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and the National Research Council, Preparing for the 21st Century: Technology and the Nation's Future.

[82] Robert M. White, US Technology Policy: The Federal Government's Role, September, 1995, A paper commissioned by the Competitiveness Policy Council, p. 15.

In that sense, the university as a monolith will disappear.[83] That has already started happening. For example, centers and programmatic areas are emerging and often replacing old divisions along department and even school lines. Dr. William Wulf, interim president of the National Academy of Engineering, recently explained,

Information technology is about to be a very major stress on the modes, methods, and processes of the university, and much more quickly than most of us are anticipating. ... Information technology will challenge the notion of the university as a place, or at least cause the university to redefine the campus. ... Ahead could be small, personal schools delivering high-quality education and informed discourse with access to the same excellence identified with the research universities.[84]

Landow points out,

The digital university is coming into being to remedy the shortcomings of the present non-digital one. In the jargon of the technologists, this change is not technology - but need driven, which is to say that those instructors and scholars who eagerly grasp the new potential of the digital word and digital university do so because they as teachers and scholars need to, though like all solutions to major problems, the electronic university will confront us with a range of new questions and issues.[85]

Universities have not yet taken full advantage of the productivity gains promised by information technology.

Governments need to raise the standards of education and skills to let their economies take full advantage of IT (information technology) and the expansion of knowledge industries. Education is one of the few sectors which has so far remained largely outside the technological revolution.[86]

While computers and the Internet offer many opportunities for distance learning, Blinder and Quandt suggest that they have not yet improved learning in the traditional classroom environment.

Since students started to submit term papers written with word processors, the appearance of the papers has greatly improved. Lines of text are justified, spell-checkers catch most spelling errors, footnotes fit neatly on the page, and so on. But the thinking has not improved, and the quality of the research has sometimes deteriorated.[87]

We must learn how to use technology to improve college and university education while reducing its price to the consumer. As with health care, government has been unable to address the root cause of the college cost problem. For example, it has been noted that tax breaks for families paying college tuition is bad tax policy and worse education policy and it fails to address the fundamental problem, stationary or even reduced productivity.[88] Further federal subsidies (either research grants or tuition subsidies) are likely to increase the demand

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[83] Professor Elias Carayannis, George Washington University, email communication to Potomac Knowledgeway.

[84] Chemical and Engineering News, "Working to Calm Research Jitters", March 24, 1997, p. 36

[85] George P. Landow, "Newman and the Idea of an Electronic University", essay in The Idea of a University, Yale University Press, 1996, edited by Frank M. Turner.

[86] The Economist, "A Survey of the World Economy", September 28, 1996, p. 45.

[87] Alan S. Blinder and Richard E. Quandt, "The Computer and the Economy", The Atlantic Monthly, December, 1997, p.31.

[88] Lawrence E. Gladieux and Robert D. Reischauer, "Higher Tuition, More Grade Inflation", Washington Post National Weekly Edition, September 9-15, 1996, p. 26.

for college and, therefore, increase the cost.[89] We can expect states to increasingly look for piecemeal, non-systemic, silver-bullet solutions (tenure modification, more federal R&D funds, increased student loans, increased solicitation of contributions from alumni, tax credits for education, etc.) to the education cost escalation problem. These efforts are not systemic and only delay addressing the issue as a system.

Universities would not have lasted for nine centuries if they were not adaptable to the circumstances of the time. Lewis Perelman believes the college education system is currently in a metastable state which will change very rapidly well before planned reform of the system comes to any conclusion. He says that if he were a college president,

> *I would get rid of all the old buildings and bricks and mortar and grounds and go virtual, but not go virtual just to become a more efficient diploma mill, which I think is a loser, but to really focus on what I think the market wants, which is know-how - I would create a know-how market.*[90]

Miller and Dunn argue that the virtual university will be a learner-oriented, not professor-oriented institution, that provides educational services at the place, time, and in the style desired by the learner. Learners will have considerable flexibility in choosing courses and they will not be restricted to a single college or university. The virtual university will have a shamrock organizational structure, a lean management structure, make full use of communication technologies, and have extensive concentration on quality. Miller and Dunn predict that developers and vendors of courseware will market directly to the public in collaboration with universities and colleges that have pre-approved the courses.[91]

Although distance learning and the virtual university are certain to grow, the need for person-to-person contact will retain some level of importance. Hopefully, these emerging forms of knowledge delivery will liberate university professors to have more not less - and more focused - contact hours with students. Information and communication technology may permit the education process to transition to a massively parallel mode of one-on-one instruction both virtual and real, with a lot of contact hours. Professors see this pattern emerging in their use of email and the Web in classes, complemented with person-to-person meetings as needed. Very effective interactions often occur between students and faculty while one or the other is out of the country. The reengineering of universities can potentially do away with tasks unrelated to their primary mission, informing and educating people.[92]

The question "for whom the universities will survive" is also a key issue. There is already a strong trend of emerging corporate universities and for-profit, one-stop-shop, mass-customized "education delivery" entities. In 1996 and 1997 Lehman Brothers[93] conducted major conferences reviewing the business opportunities in education. Lehman Brothers' business analysis is based on the belief that large opportunities will exist in the future for companies that provide timely, technologically current and relevant education services and content in a cost-effective manner to all age and skill levels. Virtual colleges, e.g., New York University School of Continuing Education, University of Phoenix, and the University of Alaska Southeast, offer what is called “asynchronous” learning networks where students can commute by modem 24 hours per day without having to adhere to rigid schedules. About 18% of these programs concentrate on business, 16% concentrate on engineering, and 10% concentrate on health services.[94]

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[89] Virginia I. Postrel, "Clinton's Education Inflation", The Washington Post National Weekly Edition, April 7, 1997, p. 21.

[90] Educom Review, “Barnstorming with Lewis Perelman”, March-April, 1997.

[91] Myron M. Miller and Samuel L. Dunn, “From the Industrial to the Virtual University”, Futures Research Quarterly, Winter 1996, pp. 71-84.

[92] Carayannis, email communication to Potomac Knowledgeway.

[93] Lehman Brothers, Second Annual Education Industry Conference, February 11, 1997, New York, NY.

[94] Business Week, “Hitting the Books At a Virtual Campus”, November 11, 1996.

The University of South Carolina (USC) has been delivering distance education for 20 years. It has finally grown to the point where USC has more engineering students in graduate programs via telecast than in the classroom. As one would expect, the distance learning model is considerably less expensive to implement than the traditional model of classroom instruction; therefore, it can serve as a "cash cow" to subsidize university research or it can lower the overall cost of a college education.

More than 30 states now have continuing education requirements for professional engineers. USC is currently negotiating with Fluor Daniel to provide customized courses for their continuing education credits needed for recertification of professional engineers. These courses will include web based learning, CD ROMs, live video, and point-to-point video conferences between professor and student. The full suite of courses needed for recertification of professional engineers presents a real financial opportunity to universities.

There is, however, a reason why Oxford still exists and why we still quote Socrates. To understand this, one must make a distinction between informing and educating students to think critically. To not make this distinction could put the U.S. on a path where it ends up with increasing numbers of to-the-minute informed, albeit uneducated, fully malleable and dispensable human capital whose role in life is limited to that of bureaucrat. Academics are entrepreneurs of the mind and are in the business of growing enlightened individuals. Technology has a place in that vision as an enabler of an educational renaissance, but it is not the entire answer. On the other hand, technology can and will lead to cost reduction while simultaneously increasing quality.[95]

Because the budgets of public universities are being increasingly scrutinized by policymakers, universities are now starting to act like businesses. At some schools, courses for distance education are being delivered by a private corporation which hires university professors. This entrepreneurism will work until the universities realize they are losing market share. At that point, additional regulations will be imposed on professors and university administrators will demand a piece of the action. One can envision a situation where universities are competing with their professors for business. Other universities may file Chapter 11 or sell parts of the university to corporations. With the emergence of HMOs and their restrictions on medical charges, university hospitals are being sold to private entities because they no longer serve as "cash cows". This practice could well expand to other parts of the university.

Coates, Mahaffie, and Hines predict the following for education in the year 2025,

> *Educational tools and apparatus are everywhere. Although nearly all children (96.3%) go to a public institution for schooling, the experience is hardly like what was provided in the schools of the 20th century. The in-classroom learning time has shrunk greatly, and the schools are directed at physical, social/interpersonal, and artistic development. The educational components of traditional reading, writing, and arithmetic are split 60/40 between school and home. For high school students, the shift has been even more striking to a 40/60 split. High school is primarily for interpersonal development, hands-on activities, and group activities such as teams, theater, and song.*
>
> *The typical student now enters college with one year of advanced placement, and it is not unusual for extremely bright students to earn two-and-a-half years of advanced placement. The college is primarily a social acculturation institution for youth and young adults. It has also become a site for continuing education by people of all ages.*
>
> *The sea change in education in the United States has been the shift from primary, secondary, and tertiary (college) education to quaternary education, that is, lifelong,*

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95 Carayannis, email communication to Potomac Knowledgeway.

individualized education. The sites of quaternary education are 50% at home, 15% at work, and 35% elsewhere.[96]

Many have proposed abstract roles for universities in the future. Sinnott and Johnson[97] have explored how universities must be reinvented or transformed to cope with emerging realities. They propose:

- The university must see the big picture as well as the little picture and reclaim the role of philosopher and lover of wisdom.
- The university should accept its mission as one serving many minds within the one mind and serve the learner as a world citizen as well as the learner as a next door neighbor.
- The university should fill the role of displaying for the learners what things can possibly mean and present alternative views of what is and what is possible.
- The university should accept as its main role the development of human potential. It must recognize that it is counterproductive to prepare people for jobs when no one is able to make even a good guess about where world or U.S. economies are headed.
- The university should restructure physically as a problem-focused, multi-site, physically-dispersed campus with each university devoted to the solution of one major human problem. All study and research must be cross-disciplinary with every problem considered in systems theory terms.

E. Research University Reform Recommendations.

We are increasingly seeing calls for education reform in the news.

Reform in higher education has been hampered by a near absence of strategic management, as well as by institutional traditions such as tenure that actually act as disincentives to productivity. And so the process of meaningful reform in the ivory tower grinds along at a snail's pace. Higher education will pay a price for resisting society's demands. Highly selective colleges and research universities probably can afford to ignore society's reform call. But most enrollment-dependent institutions face major revenue shortfalls and increased competition from proprietary institutions. ... The only realistic answer is growth in learning and teaching productivity, which will bring down costs and produce better prepared students. ... The time is right to challenge the worn-out and ineffectual paradigms of the ivory tower and to embrace the sometimes painful but essential process of reform. [98]

Reform that results in high-quality, low-cost, up-to-date education available around the world is an awesome challenge equal to that any government has ever undertaken.

Pelton[99] proposes the following reforms to improve US education:

- Deregulate and stimulate competitive learning systems.

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[96] Joseph F. Coates, John B. Mahaffie, and Andy Hines, 2025: Scenarios of U.S. and Global Security Reshaped by Science and Technology, Oakhill Press, 1997, p. 54-55.

[97] J. D. Sinnott and L. Johnson, Reinventing the University: A Radical Proposal for a Problem-Focused University, Norwook, NJ: Ablex Publishing Corp., 1996.

[98] USA Today, "College Costs Too Much, Fails Kids", July 17, 1997, p.15A.

[99] Joseph N. Pelton, "Cyberlearning vs. the University: An Irresistible Force Meets and Immovable Object", The Futurist, November/December, 1996.

- Redefine learning to instill concepts of teamwork, critical thinking, and continual learning in students.
- Embrace global education systems.
- Eliminate credit hours and degrees and develop new scoring systems.
- Reinvent academic research to include interdisciplinary and multidisciplinary learning and eliminate the publish or perish paradigm.
- Emphasize experiential learning by making use of cyberspace.
- Use the best new educational technologies.
- Beware of the danger of megatraining.
- Make higher education relevant to current societal needs and not just academic standards of the past. Learning must become a much different and ongoing lifelong process.
- Adapt to the coming era of the global brain and the globalization of education.

It is our judgment that all of the above reforms are important and will be achieved if two of the reforms are introduced by government. First, we must introduce competition into education. To do this effectively probably requires public entities to get out of the business of owning and operating education institutions. The public can still subsidize education, but it must do so in ways that promote competition rather than distort or inhibit competition. The best way to do that is to subsidize students, not educational institutions. Private education providers will implement the other reforms, not because they are required by government regulations, but because their customers demand them.

Second, we must develop new ways of scoring education. The accreditation process must be focused on accrediting the educated, not the process or institution used to provide the education. Only then will consumers be able to make informed decisions on which college or university to attend and only then will employers be able to identify those who have made considerable personal investment in learning. State legislatures need not burden themselves with attempting to introduce a wide suite of education reforms. Two will do.

VI. Findings and Recommendations

A. Findings

a. Sensitivity to Public. The public would benefit if research universities that receive or manage ***public funds*** to support R&D sensitize every one of their employees to the ***responsibilities to the public*** that entails. Research universities focus too much on science and technology, rather than the use of science and technology to solve problems of concern to the public.

b. Public Outcomes. The public would benefit if research universities that perform federal R&D would apply ***public outcome*** metrics (not to be confused with R&D process and output metrics). Every project or program conducted by research universities should be strategically linked to ***public outcomes***.

c. Boundaryless Departments. Research universities that receive Federal R&D must recognize that the major problems facing the U.S. public are exceedingly complex and multidimensional with dominant socio-economic and socio-political components. If research universities are able to bridge the internal, departmental boundaries that insulate fields of study, they can contribute to solving these problems. Universities can bring their full complement of R&D resources to bear on National problems by forging partnerships among different physical science and engineering departments as well as with economics departments, management departments, public policy departments, and business departments.

d. Entitlement Behavior. Because research universities are so widely distributed throughout the U.S., the political influence of universities is very high. However, universities that lobby Congress and the President for more funds for federal R&D are increasingly being viewed as just another special interest or entitlement driven by self preservation. Institutions responsible for the performance of Federal R&D must first look for ways to increase the ***public outcome*** from federal R&D funds. When the public sees that it gets more in return for a $10 billion increase in federal R&D spent at research universities than it gets for a 5% or $10 billion increase in Medicare, it will respond and pressure Congress to not make federal R&D a zero sum game. If the ***public outcome*** can be increased, the federal investment will be increased.

e. Hunters and Gatherers. Much of the current, inward-focused U.S. research culture was formed during a period in which the U.S. was the dominant source of innovation in the world. Rather than regard the rapid growth in new knowledge around the world as a pending apocalypse, Federal R&D programs and research universities that perform Federal R&D must increase their emphasis on the collection of research innovation from around the world and assist in the extension and transfer of that innovation to U.S. institutions.

f. Continuing Education. Research universities have underemphasized continuing education of the workforce. Society would benefit if universities would place more emphasis on continuing education, particularly by offering advanced programs to those individuals whose work requires updating due to the rapid pace of technological innovation or due to changing business practices or due to increasing quality standards. These programs should attempt to better serve the corporate student by providing education at his or her place of employment through a combination of technology and a cadre of circuit-riding professors [100].

g. University Cooperation. It is time for research universities to cooperate with one another by sharing their technological and human resources and give up their egocentric pride in each providing full educational experiences to their students. There are some good regional examples of such cooperation, for example, in the southeast, universities have banded together to provide courses on every high performance computing architecture while maintaining only one on their individual campus; and in the western U. S. governors have agreed to produce video courses and use combinations of their professors to teach advanced courses.

h. Outside Employment of Faculty. Universities could increase their value to society by encouraging many of their professors to hold part-time employment in government or industry so that they bring a real-world perspective to their students while adding value to the other sectors. There is evidence that this experience also improves the ability of professors to develop research proposals that are funded. This might be accomplished, for example, by a personnel exchange agreement between a company and a university. The outcome would pay other dividends; for example, professors who knew they had full-time employment could get off the proposal-writing treadmill which uselessly wastes large fractions of their time and allow them to focus on quality of performance.

i. Full Use of Resources. Universities and pre-college schools should disband the traditional view that summers are a time for limited curriculum offerings and that professors or teachers are on-their-own. The public has too large an investment in the infrastructure of these institutions to partially close them for such an extended period; a company's business

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[100] This is meant in the sense that rural preachers or judges traveled the sparsely populated country side in the 19th century

manager, concerned with maximizing income, would never allow such a misuse of company resources.

j. Shift Research Toward Application. Universities that wish to increase their Federal funding for research and development should do so by increasing their role in federal programs that emphasize applied research or development.

k. Productivity. Rather than defend cost escalation, research universities must increase their emphasis on finding innovative ways to increase the productivity of education, to reduce the costs of education, and to help students find part-time employment to help pay for the costs of their education.

l. Political Correctness. Universities are often caught-up in conforming to political correctness even when it is in conflict with traditional inquiry and critical analysis. Discussion of social class, racial oppression, gender discrimination, victimization, radical feminism, etc., sometimes appear to be dominated by beliefs, assertion and agile debate rather than an intellectually-based search for the truth without regard for what the truth might hold.

m. Oligopoly. State supported subsidies for in-state tuition encourage students to attend colleges and universities that are in the state in which they hold residence and contribute to oligopoly behavior. Except for the few states, e.g., California and New York, that have several high quality research universities, this practice inhibits competition and reduces the incentive for publicly-owned research universities to seek innovative ways to increase productivity.

n. Accreditation. Education accreditation has focused on accreditation of the processes, coursework, and faculty rather than accrediting the outcome of the education process, the knowledge and skills gained by the students.

o. Market Distortion. Public subsidies of community colleges and regional universities have unfairly disadvantaged private liberal art colleges and universities and inhibited competition among education providers. In response, many private colleges have either "dumbed down" their education or sought narrow specialty niches.

p. Uninformed Consumer. All educational institutions claim to be excellent. In the absence of high quality outcome-based ratings that emphasize student growth resulting from the educational process, it is very difficult for the education consumer to make informed choices.

B. Recommendations

a. Improve the Existing System - Make Federal R&D Performed by Universities Have Higher Public Value -

1. Other Nations. We should determine how other nations have maximized the ***public outcome*** of their universities' research and identify ways that the U.S. could experiment with these nations' models. We should determine if there is an international precedent for the following as well as other university roles and determine how well other nations' universities have served that role:

- university serves as the nucleus of a regional technopolis;
- university serves as a regional center for technology extension services;
- university serves as a hunter, gatherer, and integrator of innovation made around the world and transfers those innovations to companies in the host country;
- university serves as an R&D center in some area of technology where host Nation's companies are not effectively competing; and

♦ university serves as an independent, unbiased policy analysis and policy research group.

2. Historical Analysis. We should conduct case studies and synthesize existing studies of past U.S. research university roles and identify which roles have been most and which have been least cost effective in promoting economic growth and other ***public outcomes***. These case studies should include: (I) examination of university-based engineering research centers to determine whether or not these should be further encouraged and promoted, (ii) comparison of the long-term economic return from basic research to applied engineering research, (iii) sector-to-sector comparison of the private and public or social return of university research that supports major industrial sectors to determine which sectors are most affected by university research, and (iv) identification of the stage of evolution of the industrial sector where university research has the highest value.

3. Most Capable Practitioners. Vannevar Bush argued that most of the significant progress in a scientific field is generated by a relatively small group of the most capable practitioners.[101] We should conduct selected case studies of university research and quantitatively assess how well this premise holds today, and, if it does hold, recommend how this should impact the distribution of federal research funds to universities.

4. Peer Review. Many studies have lauded the peer review process that is often used in selection of research proposals submitted to the federal government by universities. Others see peer review as dominated by a megaresearch university oligopoly that does not welcome new members. Still others argue that the quality of university research is less important than its teaching value. The U.S. should make an **objective, quantitative** analysis of the peer review process, examine the ***public outcome*** from other alternatives for distributing federal research funds, and make recommendations to Congress regarding the importance of peer review in assuring that the value of ***public outcomes*** well exceed public costs. The social cost of preparing unfunded proposals must be included in this analysis.

5. Teaching Versus Research. University administrators often laud the value of research in teaching. Others argue that as university research has grown, undergraduates are increasingly taught by graduate assistants and other irregular faculty, research takes precedence over teaching, the number of students in the classroom grows, and the costs of undergraduate education are increased to finance graduate school research. An objective, competent U.S. institution with no vested interest in the outcome should make a quantitative, cost-benefit assessment of the impact of university research on the cost and quality of undergraduate education.

6. IP Ownership. We should examine the practice of universities owning intellectual property gained through federal funding of university research and determine if this practice serves the long-term interest of the U.S. public.

7. Science Roadmaps. The industrial leader, Bob Galvin, Chairman, Motorola, proposed that federally funded U.S. research should be based on science roadmaps.[102] Others have argued that all federal research should be strategic in design with an expected or potential path to ***public outcome*** identified prior to conducting the research. We should assess the value of science roadmaps and strategic research for federally funded science research and, if they show promise for increasing the ***public outcome*** from university research, recommend a process to Congress and the President for how science roadmaps and assurance of strategic content could be integrated into National innovation policy.

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[101] This position of Bush was brought to the attention of the IEEE R&D Policy Committee by member Robert L. Feik.

[102] Mr. Galvin made this proposal at the IEEE Technology Policy Council Symposium, June 10-11, 1996, Washington, DC.

8. Research Culture. In recent years corporate management of R&D has undergone many changes with industrial research groups having to constantly reinvent themselves. In the meanwhile, university research has changed relatively little with many researchers studying the same topic throughout their entire career in academe. John Armstrong, retired vice president of science and technology at IBM, remarked,

> *In this endeavor of institutional reinvention, the research culture that young scientists bring to industry from their universities is almost entirely useless. We spend a lot of time teaching our people how to think straight about science and technology and their relationship to industry.*[103]

We should examine the university research culture and identify how it can be changed to produce graduates that are better prepared to contribute in an industrial environment.

9. Research and Immigration. Federally-funded university research should not be a vehicle for making careers in engineering and science unattractive to ***U.S. citizens***. We recommend that the pros and cons of Congress giving preference to federal R&D funds that support research by faculty and graduate students that are ***U.S. citizens*** be determined.

10. Metrics. We recommend that Congress and the President increase expectations of ***public outcome*** from all universities that perform federal R&D and institute metrics to measure ***public outcome***. Federal agencies that fund university research must be organized and managed so that those university researchers that maximize the ratio of ***public good*** to public cost in the execution of their research are rewarded by budget growth and those that are not successful are penalized. To accomplish this, government must recognize and refuse to accept anecdotal evidence of success from performers of all federal R&D and shift to a ***public outcome***, metrics-based evaluation system.

11. Tax Incentives. We recommend that Congress and the President offer tax incentives for companies to form partnerships with universities for those cases where it can be shown that the potential for ***public good*** accruing from the partnership exceeds the reduction in lost tax **revenue.**

12. Internet Education. We recommend that Congress institute a program to study the relative benefits of an Internet-based or satellite-based education system and, if this system shows promise, propose roles for the federal government to play in promoting its development and use.

Appendix: K-12 Education -
Student Preparation for the Research University Experience

A. Background

The U.S. education system is a complex system of publicly-owned and operated and privately owned and operated schools. These schools provide K-12 education, undergraduate education, vocational education, technical education, and graduate education, the last of these at research universities. A simplified model of this system is shown in Figure 1. Because of the quality of education provided by the U.S. college and university system, particularly that provided by U.S. research universities, and the uniqueness of the role of the U.S. in economic, political and military affairs around the world, students from around the world are eager to participate in this system.

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103 John Armstrong, "Reinventing Research at IBM", in Engines of Innovation, edited by Richard S. Rosenbloom and William J. Spencer, Harvard Business School Press.

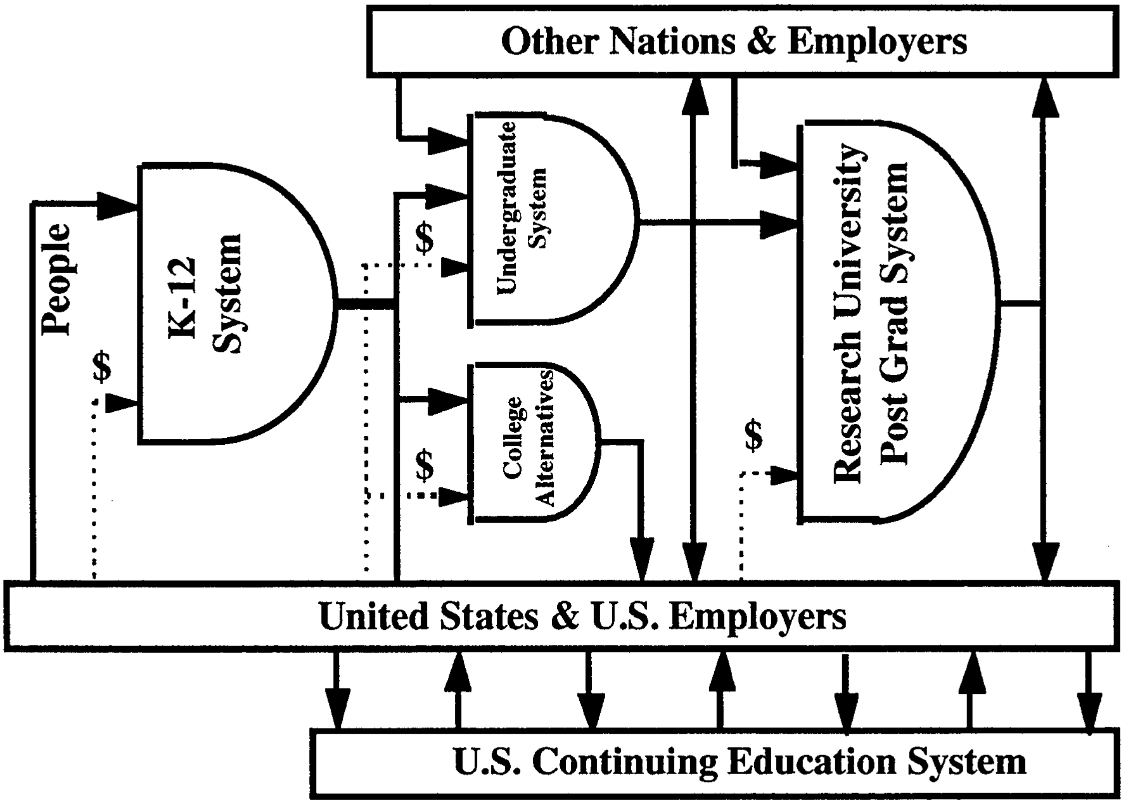

Figure 1: Illustration of people and funds flow in the U.S. education system. We show each major element of the U.S. education system as an AND gate that takes inputs of students and funds and produces graduates as outputs. For private schools, students and funds are the primary inputs; for public schools, the input of the political system is also significant.

In 1995 the United States spent $668 million or 9.2% of GDP on prekindergarten through post secondary educational services and content. Of this total, $318 billion was spent on K-12, $189 billion was spent on post secondary, $60 billion[104] was spent on workforce training, $45 billion was spent on the consumer market for education products, $30 billion was spent on pre K, $10 billion was spent on training programs, and $10 billion was spent on child reform. In 1992 U.S. public education expenditure per child was $11,880 and was only slightly exceeded by that of Switzerland, was almost identical to that of Japan, was approximately two times that of France, Austria, Belgium, and Denmark, and was approximately 50% higher than that spent by Sweden, Norway, and Ireland.[105] We have nearly 60 million (almost 25% of our population) full- and part-time students enrolled in courses throughout the U.S. Education employs 55% of local government workers and 45% of state workers.[106] Education is big business and at the local, state and national levels, education has a major voice in the political system.

Despite our massive National investment in education, several concerns surround our education system. These concerns have three primary components: (a) the quality of K-12

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[104] Most reports of U.S. companies annual investment in training quote figures in the $50 billion to $60 billion range for formal training. Informal training costs, those training efforts not reported by companies, are estimated to range between $180 billion and $200 billion per year. See, for example, Information Technology Association of America, Help Wanted: The IT Workforce Gap at the Dawn of a New Century, February, 1997, p.35.

[105] Lehman Brothers, Second Annual Education Industry Conference, February 11, 1997, New York, NY.

[106] Ibid.

math and science education is thought to be inadequate, (b) college costs are imposing great hardships on middle income families, and (c) the U.S. has failed to design an education system that promotes and offers education from cradle to grave. In the following we address the K-12 education problem and emphasize how research universities are being impacted by it.

B. Evidence Of Poor Preparation for the Research University Education.

a. The data. In 1996 international exams[107], U.S. students performed at almost exactly the international averages in both mathematics and science but were behind the scores of students from Japan, South Korea, Singapore, the Czech Republic and Hungary and roughly the same as students from England and Germany.[108] Comparisons of K-12 scores around the world demonstrate that countries with one-half the per student investment of the U.S. are matching or exceeding the examination performance of U.S. students. Although U.S. fourth-graders were second only to South Korea in science, eighth grader's scores were only slightly above average. Singapore, the leader in both math and science scores by a considerable margin, expects children to be able to read and write in two languages and do simple arithmetic prior to entering the first year of formal schooling. In addition, parents invest in private tutoring outside of the formal classroom to ensure the success of their children in the classroom.[109] From a very early age Japanese children are taught that learning is an enjoyable part of life and that the motivation for learning is resident in the student, not the teacher.[110] Our considerable investment in education is not producing the performances many Americans expect, particularly companies that are seeking manufacturing employees.

Polls show that 62% of Americans believe that our educational system will get worse instead of better.[111]

There are three schools of thought regarding the K-12 math and science education issue. One group argues that the root cause of poor math and science scores is poor reading skills. Some argue that these stem from replacing phonics with whole word recognition as the fundamental way of teaching reading in the early grades.[112] A second group argues that the issue is strictly an inner city issue whose root cause is socioeconomic and regardless of the effort invested in education, poor math and science scores are only the symptom of a much more severe social problem. A third group argues that the K-12 problem is not just limited to inner city schools, it is also widespread in suburban and rural schools. This group also believes that poor math and science scores are not necessarily a consequence of poor reading skills, rather they argue that poor teaching skills and lack of study time are the likely culprits.

b. Corporate interpretation. Norm Augustine, Chairman of Lockheed Martin, has lead National studies of education. His concerns about K-12 education summarize the perspective of a majority of senior executives from major U.S. corporations. He notes that even though there have been improvements in K-12 education, these improvements are inadequate to meet company needs for employees. In advocating the need for education standards, he explains,

> *More students are doing better than they were a decade or two ago. The bad news is that they - and we - are not performing nearly well enough to meet the challenges of the 21st century. ... Only 30% of fourth-graders, 30% of eighth-graders, and 36% of*

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[107] Third International Math and Science Study, TIMSS.

[108] For a comparative tabulation of TIMMS math and science scores by nation, see, for example, The Economist, "Who's top", March 29, 1997, p. 21.

[109] Alan Lim, Letters to the Editor, The Economist, April 19-25, 1997, p. 8.

[110] Gail Benjamin, Japanese Lessons: A Year in a Japanese School Through the Eyes of an American Anthropologist and Her Children, New York University Press, 1997.

[111] The Washington Post National Weekly Edition, "What About Us?", September 23-29, 1996, p. 9.

[112] Personal communication, Mr. Charley Richardson, IEEE senior member, to James Gover.

twelfth-graders reach or exceed a proficient level in reading. Further, only 21% of fourth-graders, 24% of eighth-graders, and 16% of 12th-graders reach or exceed a proficient level in math. ... Many of those who do graduate from high school arrive at the doors of industry unable to write a proper business letter, fill out simple forms, read instruction manuals, do essential mathematical calculations, or understand basic scientific concepts.[113]

Murnane and Levy point out that it isn't K-12 education that has changed, it is jobs that have changed and K-12 education has failed to prepare graduates for these changes. Jobs consisting largely of routine steps that could be performed by high school graduates now require discretion and reasoning. They argue that today's jobs require the six skills shown below.[114]

- Reading at a ninth-grade level
- Performing math analysis at a ninth-grade level
- Problem solving
- Communicating orally and in writing
- Using a computer for word processing and other tasks
- The ability to collaborate in diverse groups

Whitehead interprets the research of Murnane and Levy to mean that the skills that explain much of the growth in the wage gap between high school and college workers can be learned by students before they finish high school. Whitehead points out,

If Murnane and Levy are right, what it takes to earn a middle-class living needn't be a two-year or four-year degree or a training certificate; a K-12 education can impart these skills, increasing the share of students who master them and get the kinds of math and reading scores that were achieved by the high scorers in the classes of 1972 and 1980. Teaching necessary skills, the authors assert, should be the chief objective of our schools. ... What it takes to qualify for a job in a modern auto plant or at an airline ticket counter is probably pretty close to what it takes to do the work in the majority of the nation's colleges today. As such workplaces have become more demanding, college has become less so.[115]

c. Abstract analysis. Marshall offers an interesting interpretation of what has been happening in education in terms of the emerging fields of **complexity and chaos.**

It is my belief that the espoused crisis in public education is predominantly a crisis about learning and that it is fundamentally grounded in the dynamic integration of two new domains of inquiry:

1. The paradigm shift from a machine-based "clockwork" conception of the universe to a complex adaptive perspective.

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113 Norman R. Augustine, "A New Business Agenda for Improving U.S. Schools", Issues in Science and Technology, Spring 1997, p. 58.

114 Richard J. Murnane and Frank Levy, Teaching the New Basic Skills: Principles for Educating Children to Thrive in a Changing Economy, The Free Press, 1997.

115 Ralph Whitehead, Jr., "High School and the New Jobs", The Atlantic Monthly, September, 1997, pp. 114-116.

2. The paradigm shift from understanding the brain as a computer to be programmed and learning as a linear process of information accumulation to understanding the brain as a dynamic, self-organizing neural network and learning as a natural, active, and messy process of pattern formulation and constructed meaning. ...

> *The insights of complex adaptive system theory and learning theory have fundamentally altered these (schooling and learning) metaphors and have radically reframed the discourse on learning and schooling; in place of machine-based metaphors are fluid, organic, and biological metaphors that place schooling structures in dynamic opposition to our new knowledge.*[116]

We pose the following question - **can a public education system that is and must be sensitive to local political issues be fluid and adaptive to emerging and radically different new ideas and metaphors of learning while retaining the homogeneity and consensus demanded by the political process? We think not. Therefore, while in the following, we review numerous interpretations of failures in public education, we think that the U.S. public education system is about as good as a public education system can be made to be. We have come to believe that further improvements will only come from radical redesign of the system that will place the system under market forces rather than political forces. Market forces will replace the homogenous public education system with a wide variety of schools each tailored to the needs of a particular group in the market.**

d. Learning and reading disabilities. U.S. K-12 students have not competed as well on international exams as most Americans expect. It is thought that learning disabilities may account for some of the mediocre student performance. About ten years ago Congress directed the National Institutes of Health to study learning disabilities and determine how reading skills are developed. NIH studies of 2,500 young children show that 20% have substantial difficulty learning to read with reading problems being just as common among those with above average intelligence as they are among those with below average intelligence. Reading impairment was almost as common among those who grew up being read to by family members as those who were not.

> *NIH researchers say the problem lies in the parts of the brain that process the written work. For many children the disorder is hereditary. For others the problem is insufficient exposure to language and reading. Nevertheless, about 96% improve after intensive help. ... The NIH has concluded that both literature and phonics practice are necessary for impaired and unimpaired children alike. The phonics component is vital for the 40% of children for whom work recognition is difficult. ... These findings underscore the need to do a better job of training teachers. The NIH researchers found that fewer than 10% of teachers actually know how to teach reading to children who don't get it automatically.*[117]

It is well known that children with learning disabilities are many times more likely to be hyperactive, delinquent and to end up in prison. At this point they lose their potential to be social assets and instead become social liabilities that cost $25,000 per year to house in a prison that cost $125,000 per bed to construct. Their annual room and board is about equal to the annual tuition costs of a private research university.

> *Some educators argue that children who have difficulty learning are "curriculum disabled" by teaching strategies that promote vague goals like self-esteem over traditional skills. ... Ms. Bertin (Windward School in White Plains, N.Y., a private school for the learning disabled) and her colleagues are incensed by the "whole language"*

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[116] Stephanie Pace Marshall, "Creating Sustainable Learning Communities for the Twenty-First Century", in The Organization of the Future, edited by Frances Hesselbein, Marshall Goldsmith, and Richard Beckhard, The Drucker Foundation, 1997, pp. 177-188.

[117] New York Times, "Teaching Johnny to Read", January 25, 1997.

system of reading that swept America during the 1980's. The approach, they say, often forsakes phonics, grammar, and the drill-and-practice many children need to become competent readers and writers. Whole language still has many disciples, but California renounced it after the state's students finished 39th, tied with Louisiana as the worst readers among the states tested.[118]

e. The whole reading mistake. Mr. Charles Richardson, a professional engineer, has devoted 15 years of his career to merging his engineering and education knowledge to improve public education and especially reading instruction. He and his wife operated a remedial education center on Long Island that has successfully diagnosed and treated the reading and mathematics learning problems of 2,700 students. Mr. Richardson is among those who suggest that poor reading skills derived from emphasis on whole reading at the exclusion of phonics are the cause of poor math and science scores.

From my observations and from looking at the symptoms, it's become apparent that malpractice in early reading methodologies is undermining basic reading reflexes necessary for full language development. ... We have a serious systemic problem, and we will not be able to make substantive improvements in math and science education unless we first address the reading and literacy situation. The educational community is not taking a hard, searching look at its literary curriculum precepts. It's going against its own best research in charting corrective or preventive strategies, which would indicate that a phonics-first approach to reading is more effective than other methods..[119]

Bill Honig, when he was state superintendent of public instruction in California instituted many education refoms including introduction of the classics of history and literature. Recently, he has recanted some of the refoms introduced during his tenure. The particular policy that has received most of Honig's criticisms is whole language reading instruction. In each of the past three years California's state legislature has passed bills designed to move reading instruction away from whole-language and move it toward the phonics method. The general consensus is that California made a major mistake in embracing whole-language reading instruction.[120]

Edward Rondthaler, President of the American Literary Council, points out that the English language has 44 phonemes or spoken sounds that are spelled in 400 different ways. The 70 most common spellings of these phonemes will correctly spell about 85% of words. To master spelling by phonics, one must remember how to spell the 44 phonemes as well as the irregularities. Apparently about 20% of people have difficulty remembering all this.[121] Some find whole word reading to be an aid to learning reading.

f. The whole math mistake. Others are concerned that low performance on math exams derives from 'whole math' teaching methods.[122]

*The whole-math disaster began in 1989 when the National Council of Teachers of Mathematics issued a set of standards declaring a new approach to be in order. No more **drill and kill**, as whole-math people like to call traditional teaching. Instead, from kindergarten on, there would be a calculator in every hand so that young minds would be free of irksome chores like addition and multiplication and thus able to take on higher-order tasks such as inventing their own personal methods of long division. No more teacher as **sage on the stage**, instructing a class of students; a teacher would*

118 New York Times, "Betrayed in the Classroom", January 13, 1997.

119 Charles M. Richardson, "Are We Operating Scientifically on Pre-College Education?, IEEE Impact, December 1986.

120 Nicholas Lemann, "The Reading Wars", The Atlantic Monthly, November, 1997, pp. 128-134.

121 Edward Rondthaler, Letter to the editor, The Atlantic Monthly, February, 1998.

122 Lynne V. Cheney, Senior Fellow, American Enterprise Institute, "The Latest Education Disaster: Whole Math", The Weekly Standard, August 4, 1997

serve instead as a ***guide on the side****, offering non-judgmental questions and comments to groups of students working out their own mathematical meanings.*

Skeptics of whole math are as rare in colleges of education as opponents of postmodernism in English departments. Indeed, as in English departments, those most loyal to the prevailing mode of thought are most rewarded. John Dossey was chosen to be the author of one textbook and is credited as conceptualizer for another in Addison-Wesley's whole-math series. This second book, Focus on Algebra, has been dubbed Rainforest Math by Marianne Jennings, who observes that environmentalism and Third-World concerns seem to loom larger in it than equations.

g. Teacher training. A recent comprehensive study of U.S. teachers found that one-fourth lack college training in their primary classroom subject.[123] An international survey of math and science education, involving more than one-half million K-12 students from 41 countries (11,000 U.S. students from 180 U.S. public and private schools), revealed that U.S. students spend more time in the classroom studying math and science, have longer and more frequent homework assignments, and watch no more television than students in Japan and Germany. This study found U.S. math and science education to be deficient in teaching style, e.g. math and science are taught as exercises of plugging into formulas rather than using reasoning skills to hone understanding of the underlying concepts. It was also determined that the U.S. math and science curriculum lagged those in other countries, was not as well focused, and U.S. textbooks were often inferior.[124] There was concern that U.S. teachers dwell too much on praising students for simple accomplishments and lack the patience to let students gradually discover lessons on their own.[125]

h. Engineers' perception. While some deny the inferiority of math and science teaching in the U.S. K-12 system, engineers throughout the U.S. have known for several decades that their children's math and science teachers were often encouraging rote memory rather than reasoning skills. Education certifying bodies are unwilling to permit U.S. engineers, many of whom have been displaced from their engineering jobs or retired early (because of age discrimination and the availability in the U.S. job market of lower-paid, U.S.-college-educated immigrants) into the classroom to teach math and science unless they first meet the demands of teacher licensing and participate in a multi-year college of education program to help them hone their teaching skills. Education colleges like this requirement because it provides them with students. The engineering profession is filled with engineers who could make immense contributions to math and science education, but most of them are too independent to waste their time walking the gauntlet of preservice education and many have low tolerance for the labor-union-like work environment.

With only 3.3 wage earners per social security beneficiary (in comparison to 5.1 workers per beneficiary in 1960) and projections for 2.0 workers per beneficiary in 2030, it is in the best interest of the U.S. to keep citizens working and off the social security rolls as long as they are able to contribute.[126] (Note that 1995 social security revenues exceeded outlays by $65 billion and in 10 years are expected to exceed outlays by more than $130 billion. For the next 6 years after that maximum, revenues are expected to exceed benefits. About 16 years from now benefits are expected to exceed revenues with the social security trust fund being

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123 Rene Sanchez, "Teachers, No Longer the Best or the Brightest", The Washington Post National Weekly Edition, September 23-29, 1996, p. 32.

124 Rene Sanchez, "Low Marks in Math and Science," The Washington Post National Weekly Edition, November 25-December 1, 1996, p. 31.

125 Rene Sanchez and Robert O'Harrow, Jr., "U.S. Struggles to Solve It's Math Problem", The Washington Post, Jan 23, 1997, p. A01.

126 The Economist, "Social Securities?", December 14, 1996, p. 28.

exhausted between 31 and 34 years from now.[127] These projections are based on current social security tax and benefit practices.)

Engineers retiring early could help fill the U.S. gap in math and science teaching competence, delay engineers acceptance of social security funds, and help fill the acute teacher shortage that is anticipated as today's teachers retire. Because of attrition and retirement, the U.S. needs to add about two million new teachers over the next decade. Between now and 2006, the number of teachers is expected to grow from 2.7 million to 3 million.[128]

While many practicing engineers, scientists, and mathematicians are willing to contribute their skills to assist colleges of education in building stronger teacher preparation in the math and science areas, such activity is viewed by some university researchers as being of far less value than research. Universities perpetuate this situation by excluding or minimizing the value of K-12 activities in consideration for tenure and promotion.

i. Textbook and lesson quality. In testimony to the U.S. House of Representatives Science Committee, Dr. James Hiebert, Professor of Education at the University of Delaware, argued that the major differences in teaching between Japan, Germany and the U.S. lies more in the quality of lessons than in the skills of teachers. For example, in 62% of Japanese eighth grade math lessons, there was emphasis on deductive reasoning. In comparison, deductive reasoning was evident in 21% of German math lessons and 0% of U.S. math classes. Professor Hiebert notes that we need to shift from the prescription of general teaching techniques, i.e., teaching style, to the development of well-formed lessons, i.e., teaching substance. He explains,

> *By several criteria, U.S. lessons were less coherent than those in Germany and Japan. First, U.S. teachers switched from one topic to another within lessons significantly more than German and Japanese teachers. ... There are two ways in which the coherence of U.S. lessons get undermined. One is that teachers break the flow by engaging in irrelevant diversions. A second is that lessons are interrupted by outside events, such as PA announcements and visitors... Japanese students spend less time practicing routine procedures and more time inventing, analyzing, and proving than their German and American peers. German and U.S. students spent most of their time practicing routine procedures.*[129]

In the 1950s the PSSC program was developed for high school physics students by some of the nation's best scientists from some of our most prestigious universities. These science leaders considered their efforts a pay back to society. Today, only a few practicing scientists and engineers take the time to become knowledgeable about the high school science teaching community and leading scientists do not write high school textbooks. Richard Elmore, professor of education at Harvard, has further pointed out that textbook publishers have no incentive to develop textbooks that have focused content because the publisher is attempting to gear sales to the broadest possible cross-section of customers and to gear learning to the largely content-free standardized tests. The result is that courses are 'overstuffed and undernourished'. Elmore notes,

> *Students who do well in such a system recognize that they are being judged largely on their command of the rules of the game, which reward aptitude rather than sustained effort in the pursuit of clear expectations. All systems have a code; the job of the student is to break it. Some do, some don't.*[130]

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[127] The Washington Post National Weekly Edition, "The Myths of the Social Security Crisis", July 29-August 4, 1996, p. 21.

[128] The Wall Street Journal, "Teacher Retirements Portend Acute Shortage", July 24, 1997, p. B1.

[129] Testimony of Dr. James Hiebert before the Committee on Science of the United States of Representatives, October 8, 1997.

[130] Richard F. Elmore, "The Politics of Education Reform", Issues in Science and Technology, Fall 1997, pp. 41-49.

j. A Federal laboratory study. Around 1990 a team of systems researchers at Sandia National Laboratories investigated the K-12 education problem. Their findings[131] included:

- On average, using popular measures of quality, U.S. K-12 education has steadily improved; however, it is unclear what the rate of improvement must be to position the U.S. for economic growth in the 21st century. It is also unclear that the popular measures of education quality are the right measures.

- U.S. suburban and rural schools are excellent and students from these schools compete very favorably with students from around the world. However, students from inner-city schools trail far behind both National and international averages and significantly lower the overall U.S. average. The U.S. K-12 education problem is almost entirely an inner-city education problem and it is largely a socioeconomic issue rather that an educational issue. While vouchers might improve suburban schools, as long as most private schools remain in the suburbs, school vouchers alone will not help alleviate the root cause of the K-12 education problem, because only a few of the parents of inner-city children can afford to transport their children to the suburbs.

- Most of the cost growth in U.S. K-12 education (between 1950 and 1990, the per pupil expenditure increased 350% in real dollars) can be explained by rapid growth in special education and escalation of fixed costs (insurance, regulations, etc.)

This Sandia study was consistent with a House Science, Space, and Technology Committee study. The House study emphasized that America's K-12 education problem was concentrated in urban schools and pointed out that in most large cities, dropout rates were high, morale of students and faculty were low, school leadership was crippled by a web of regulations, literacy rate lagged national averages, and crime, violence and drugs were creating an environment not conducive to learning.[132]

Some scholars have taken issue with sections of the Sandia study, particularly its suggestion that degradation in U.S. SAT scores could be explained by an increasing fraction of low-ranked students taking the exam.[133]

Sandia conducted this study because the Secretary of Energy had declared the K-12 education problem "to be a matter of mission for the DOE laboratories". The traditional Sandia approach to a problem such as this is to first conduct a system's study to define the problem and identify it's root cause. When Sandia did this work, the Bush administration was advocating a voucher system for K-12 education. Because the Sandia study raised doubt about whether a voucher system addressed the root cause of U.S. K-12 education problems, this research was stopped prior to its completion and publication of the early results were delayed for two years.[134] The Atlantic Monthly reported,

> *for two years the (Sandia) report - a collection of tables and statistics on everything from dropout rates and SAT scores to college degrees awarded in engineering and other technical fields - was buried by the Department of Energy, which had commissioned it. The document, said James Watkins, George Bush's Secretary of*

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[131] C. C. Carson, R. M. Huelskamp, and T. D. Woodard, "Perspectives on Education in America", The Journal of Educational Research, May/June 1993, pp. 259-310. The conclusions of the Sandia study were similar to those reached by Dr. Iris Rotberg, one of three principal researchers for the U.S. House of Representatives Science Committee report, Technology and Its Impact on the National Economy, December, 1988.

[132] Committee on Science, Space, and Technology, Technology Policy and Its Effect on the National Economy, October 19, 1988, Washington, DC.

[133] J.E. Stone, Education Consumers Clearinghouse, The Atlantic Monthly, Letters, February, 1998, p. 10.

[134] Personal communication, Dr. Charles Carson, Department Manager, Sandia National Laboratories.

Energy, was "dead wrong," and would be regarded as "a call for complacency at a time when just the opposite is required". ... Mixed reports don't make for good headlines, and qualified good news undermines the sense of crisis essential both to liberal demands for more money and to conservative arguments that only vouchers and other radical solutions will do.[135]

The reaction that the Sandia study stimulated illustrates the political sensitivity of K-12 education issues. We believe that this is the basic flaw of public education and ultimately limits its quality.

B. K-12 Education Research.

a. The need. The Sandia study highlighted the importance of conducting credible research on the U.S. education system and performing credible synthesis and interpretation of ongoing education research and education experiments. Furthermore, it highlighted the importance of this work being conducted by institutions with strong system analysis capabilities that have no vested interest in the outcome.

(Ironically, just as the U.S. is reviewing international K-12 math and science scores and wishing to attain a performance closer to that of Japan's students, Japan is attempting to develop a system more like that of the U.S. Critics of Japan's education system believe that it is the ability of America's K-12 education to educate the "best and brightest" K-12 students that makes the U.S. so dynamic and creative. Japan's education reformers are encouraging their Ministry of Education to abandon its emphasis on conformity and equality and to adopt a curriculum that encourages creativity and individualism.[136] We believe that while critics of the U.S. education system prefer to ignore the accomplishments of U.S. public education, this irony highlights the need for more and better education research.)

Dr. Rodger Bybee explained the need for education research to the House Science Committee,

It would be in the nation's interest to understand more in some areas, such as student learning; build some basic understanding in other areas, such as how effective school systems function; and, most importantly, apply what we know in all areas. To do so, we have to provide financial support for educational research. The underfunding of educational research is dramatic. A comparison between the pharmaceutical industry and education is instructive. In 1995, the United States spent approximately $70 billion on prescription and non-prescription medications. That industry invested about 23% of this amount on development and testing of drugs. In contrast, the United States spent approximately $300 billion on education in 1995, but invested less than 0.1% of that amount on educational research.[137]

b. New governance model of education. A recent study by the Rand Corporation suggests that the public school system can be improved by shifting its governance model to an arrangement like that used for government-owned, contractor-operated Federal laboratories. This Rand study proposes that contracting would radically change the way we operate our public schools while keeping them public, accessible to all, and better able to meet standards of achievement and equity.

By using public funds, local school boards would select private providers to operate individual schools under formal contracts specifying the type and quality of instruction. Contracting would free local school boards from operating schools so that they could focus on improving education policies. It would allow parents to choose the best

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135 Peter Schrag, "The Near-Myth of Our Failing Schools", The Atlantic Monthly, October, 1997, p. 72.

136 The Economist, "The Struggle to Create Creativity", June 28, 1997, p.46.

137 Testimony of Dr. Roger Bybee before the House Committee on Science, United States House of Representatives, October 8, 1997.

schools for their children. It would also ensure that schools are held accountable for meeting academic standards. Contracting would enable schools to become more imaginative, adaptable, and better suited to the needs of children and families.[138]

The U.S. may well have outlived the traditional, highly-politicized School Board System where board members are elected by popular vote. This system rejects intrusion from outside cultures and has led to the educational equivalent of regressive in-breeding. Not surprisingly, this practice is particularly pronounced in those states with the weakest education systems.

Schrage notes,

as long as so few real rewards are given for distinction and so few real penalties extracted for failure, the educational process will tend to remain lackadaisical and inefficient. ... Equally important, the schools are so riven with contradictory objectives - merit versus inclusion, for example - and so loaded down with extraneous social mandates for everything from drug education and AIDS counseling to diversity training and social awareness (often imposed by the same politicians who complain about school failure) that it's a wonder anyone learns anything.[139]

Technology will soon make it possible for students anywhere in the U.S. to have access to the best instruction this Nation can develop. One of the causalities of the education technology revolution will be local political systems that have used the education system as their power base.

c. Competition in education. In intensively competitive systems, technological innovation invariably leads to productivity growth. However, in weakly competitive systems representative of a monopoly or oligopoly, technological innovation often leads to increased output, but usually demands proportionally increased input. Thus, there is little or no productivity growth. In fact, K-12 education is proud of low productivity. That is some believe the lower the ratio of students to teachers (an approximate measure of gross labor productivity), the better the education system. To realize dramatic improvement in the productivity of education it is first necessary to shift this sector from a weakly competitive status to an intensively competitive status. When the competition among education services providers is intense, these providers will seek out technology to improve their productivity and increase or maintain profits.

Technology is expected to have immense impact on the quality of K-12 math and science teaching and future models of education may be revolutionary. School districts, and even colleges, remain fiercely autonomous, seeing their mission and purpose through the eyes of their local, tax-paying constituents. This governance structure was necessary as long as education was labor intensive and limited by the distance students could travel to the local school. In that environment, the aggregation of students, teachers and resources was sensible and productive. Today, however, telecommunications technologies are challenging the fundamental tenets upon which our entire educational system has been constructed. ... The need to aggregate people simply to communicate with them has disappeared. We now have the capability to provide individuals, at locations of their own choosing, with vast, and rapidly expanding, collections of print and visual materials and the means to share limited resources among many educational institutions. The tools for another major transformation of American education are here today. What is lacking is widespread understanding of the power and meaning of those tools for the revolution underway -

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138 Paul T. Hill, Lawrence C. Pierce, and James W. Guthrie, Reinventing Public Education: How Contracting Can Transform America's Schools, the Rand Corporation, April, 1997.

139 Peter Schrag, "The Near-Myth of Our Failing Schools", The Atlantic Monthly, October, 1997, p. 78.

a revolution that promises to transform the role of educators by the beginning of the next century.[140]

d. Privatization and other options. There are numerous ways to move to an intensively competitive state. One way is to privatize the entire education system and partially free it from the morass of regulations that currently smother it. In a privatized system, services providers would offer education custom designed for the consumer. Those that preferred whole math or whole reading methods could seek out schools that used these methods. Students and parents that only wanted the creationist view of the origin of mankind taught could find a school that met their needs. Those that wanted prayer in the schools could have it.

While the public would no longer have a role in managing schools, the public could still fill diminished roles in funding and regulating schools, and their testing role would be increased. That is, the public would have responsibility for providing testing services that measured the knowledge and skills gained by students in various schools and tracked post school success of students. In this privatized system the education process and the concepts of graduation and degrees would be irrelevant. Public funds could be used to help offset some of the education costs for the lower economic groups and public funds could be used to support testing services that accredited the learning received by students. However, under no circumstances should any student be completely shielded from the responsibility for bearing the cost of their education.

In this new model, accreditation emphasis would shift from the institution and its process to the educated. In this free market system, unions would have lesser roles. Hoxby, a Harvard economist, has researched the impact of teachers unions on K-12 school performance.[141] She finds that unionization of teachers increases school spending by 10% per pupil, increases teachers pay by 5%, reduces class size by 1.7 pupils per teacher but does not reduce drop-out rates or otherwise make detectable improvement in education quality. In fact, unionized schools had 2.3% higher drop-out rates than non-unionized schools.[142]) In the intensively competitive system we propose, services providers will find unique ways to introduce technology to improve productivity.

As Charles Krauthammer points out, it is time for the U.S. to conduct a grand experiment for K-12 education. A voucher system could be the centerpiece of one experiment. A teacher incentive program could be the focal point of another.[143] A technology-intensive system could be the thrust of another. A completely privatized public education system with vouchers provided according to means tests could be the thrust of another experiment. This option is particularly attractive because in a privatized environment a wide variety of schools would evolve, each catering to the particular interests of families and students. In a privatized environment, rather than regulating educational institutions and accrediting their program, government could measure and accredit the education of the graduates. If experiments are to be conducted, **critical** measurement must be made an indispensable element of these experiments and the public must be fully informed of the results of these experiments.

Of course, the public education system will fight vouchers. As The Economist pointed out,

> *Never mind the "f"-word. Other words are far more offensive to some teachers. Mention the "c" word (competition) and they wince. They tut at the "s" word (selection). And don't ever say the "v" word: the idea of giving vouchers to parents,*

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[140] George Connick and Jane Russo, "Technology and the Inevitability of Educational Transformation", in The Electonic Classroom, edited by Erwin Boschmann, Learned Information, 1995, p. 15.

[141] Caroline Minter Hoxby, "How Teachers' Unions Affect Education Production", Quarterly Journal of Economics, August, 1996.

[142] The Economist, "The Toll of Teachers' Unions", October 19, 1996, p. 33.

[143] Charles Krauthammer, "Improve Elementary Schools First", Albuquerque Journal, May 25, 1997, p. B2.

to spend on either state or private schooling, horrifies them. The American Federation of Teachers calls vouchers "obscene".[144]

Cleveland provides evidence that a school voucher system can improve the overall condition of K-12 education. Cleveland offers a means based voucher system so that students from poor families are reimbursed for 90% of their annual tuition costs up to a maximum of $2500. Surveys indicate that parents of voucher students are happy with the education their children are getting and test scores in reading and math indicate that the voucher students have increased their rate of learning.[145]

e. Measuring Outcomes. Apocalypse gourmets argue that problems in K-12 education are only symptoms of an overall malaise that pervades the whole of society. Permissiveness and a lack of self-discipline and morals, it is argued, are wrecking family life, corrupting politics, and destroying the fabric of our society.[146] How and under what conditions to teach the evolutionary model of the creation of life is a topic of intense debate between educators, scientists, and creationists. Some believe that demise of U.S. K-12 education is due to an international conspiracy that intends to bring the U.S. under the control of a single world government. The fact that nation states are fissioning rather than fusing has not yet interfered with this line of thought. We prefer to not invoke an explicit conspiracy model to explain behaviors that are adequately described by implicit models built on ignorance and self preservation paradigms. Failures of public entities are principally due to the fact that they are information-deficient monopolies that inevitably evolve into a bureaucracy dominated by self-preservation instincts. Measuring outcomes threatens the bureaucracy; therefore, bureaucracy abhors metrics. Conspiracy arguments are superfluous.

The State of Kentucky offers the U.S. an opportunity to develop a research- and measurement-based model for new directions for K-12 education and new local education governance models.[147] In 1989 the Kentucky Supreme Court when hearing a case regarding the equitable distribution of education funds among Kentucky schools, declared the entire body of Kentucky school law to be unconstitutional. In March 1990 the Kentucky state legislature passed the Kentucky Education Reform Act (KERA) to reform Kentucky's entire K-12 education system. KERA emphasized the following areas of reform[148]:

- **Academic goals and their assessment and accountability**. The idea is to define what the students are expected to learn and what they are to be able to do with that knowledge. Thus, educational outcomes are prescribed. KERA also instituted a state-wide, school-level assessment program (KIRIS).

- **School Governance**. Management authority for schools was transferred from elected school boards to school based management councils consisting of a school's principal, three teachers and two parents and to the professional educators in the Kentucky Department of Education.

- **School Funding.** Since KERA was implemented, Kentucky's annual funding for public education has increased from $2 billion to $3 billion and there has been an attempt to assure an equitable distribution of these funds among public schools around the state.

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144 The Economist, "Don't Mention the 'V' Word", November 27, 1997, p. 18.

145 The Economist, "Lessons Cleveland Can Teach", November 29, 1997, p. 27.

146 Katharine Washburn and John Thornton, Dumbing Down: Essays on the Stripmining of American Culture, Norton, 1997.

147 Congressional Quarterly, "Congress Looks to Kentucky For Lessons on Education", February 28, 1998, pp. 491-497.

148 Richard G. Innes, From the Consumer's Perspective: The Kentucky Education Reform Act (KERA), unpublished manuscript provided to James Gover by Mr. Innes.

- **Nepotism Restrictions.** KERA broke-up family fiefdoms that controlled some counties' educational systems.

- **Creation of a Special Core of Trained Teachers.** KERA created a group of educators to take over problem schools and school districts.

- **Changes to Training and Certification of Professional Educators.** Teachers were allowed to spend 5 days being trained for KERA practices.

- **Inclusion of Children with Special Needs in Regular Classrooms.** KERA mandated that exceptional children be included in regular classrooms.

- **Tutorial/Remedial Services Program.** An extended program of school services including tutorial services, study halls, etc. was established.

- **Family Resource/Youth Service Centers.** Centers that provided social and health counseling services to students and their families were located in close proximity to schools.

- **Preschool Program Changes.** Preschool programs were established for those students not in Head Start including a special program for at risk four year old children.

- **Upgraded Primary for K-3 Students.** Through the third grade, children are mixed according to ability, not age, and are allowed to progress at their own pace without being graded relative to other students.

Even though some of the KERA measures are almost certain to work, it is important to fully understand how well each measure works and at what social and economic cost. While Kentucky's K-12 education reform is sweeping and offers many opportunities to learn how to improve K-12 education systems around the Nation, one cannot determine from public documents if the reformed system is working better than systems used in other states.

Mr. Richard Innes, an electrical engineer retired from the USAF, has done an analysis of Kentucky's reforms. Mr. Innes spent many years developing technology-intensive instructional programs for the USAF. He explains,

> *KERA is outcome-based education; but, its outcomes have never been stated clearly enough to determine its success or failure. Instead of methodically and systematically phasing in change, KERA simultaneously imposed a large number of new educational policies and practices. A significant number of the changes have never been implemented on a large scale, and the changes have never been implemented before as a group. This means the reform program is essentially untested. As a result, the Kentucky experience resembles a massive experiment, conducted at public expense, using at least a generation of students as its subjects. KERA's measures of academic progress and accountability have been found to be seriously flawed by a variety of respected reviewers. Reported successes of KERA are contradicted by stagnation and decline in conventional academic measures of educational achievement such as the CTBS, SAT, ACT, and NAEP[149 150], and by non-academic indicators such as dropout rates. ... Kentucky's adoption of a unique, Kentucky-only evaluation system makes comparison to other states' education performance extremely difficult. ... Reports currently heralding the success of KERA are based on incomplete and fundamentally misleading data from Kentucky's new OBE test. These claims of*

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[149] Richard G. Innes, Kentucky Education Data: Test Results and Other Indicators in Tabular and Graphical Forms, March 5, 1997.

[150] Richard G. Innes, Kentucky Education Data: Comparison of Results from the Kentucky Instructional Results Information System (KIRIS) and the National Assessment of Educational Progress (NAEP) from 1992 to 1996, March 27, 1997.

success are currently unwarranted as a thorough research program on KERA's effects has never been conducted.

As Mr. Innes' observations suggest, if states are to improve their K-12 education systems, they must have something to compare to and that should not just be their past performance. It is important to know if the performance of K-12 schools are increasing relative to their past performance, but it equally important to know if they are performing fast enough for their graduates to compete with students from around the nation and, in the global age, from around the world. A uniform set of national metrics must exist to evaluate education. We agree with the critics of metrics who argue that metrics shape behavior. Of course they do, and metrics can always be criticized. Nevertheless, using them is far better than not using them. While many think that the development of testing standards is not an appropriate role for the Federal government, we argue that it is the primary, and perhaps only role for the Federal government to play in K-12 education.

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