From Guns to Pills to Brains:

Shifting Federal Research Priorities for the 21st Century

James J. Duderstadt
President Emeritus
University Professor of Science and Engineering
The University of Michigan

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Introduction

It is both an honor and a pleasure to be invited to University of Washington to give this year's Dael L. Wolfle Lecture, sponsored by the Evans School of Public Affairs. This invitation has particular meaning for me since, as many of you know, I had the privilege of serving for 12 years as a member of the National Science Board, chairing that body during my last several years of service. Last December the nation celebrated the 50th anniversary of the National Science Foundation and the National Science Board. These two organizations, vital to American science, own both their existence and their current character to the efforts of Professor Wolfle and his colleagues. Their impact on the past fifty years of science policy in this nation has been considerable indeed.

My visit this week also provides yet another opportunity to strengthen the bonds between our two universities. There have long been close relationships and many similarities between the University of Washington and the University of Michigan:

- The University of Washington is the flagship institution in the northwest, just as Michigan is the flagship public university in the midwest.
- Our institutions are both regarded as national leaders in research, generally ranked one-and-two in the amount of federally funded research attracted by our faculties.
- We both have prominent athletic programs, not infrequently facing each other on New Year's Day.
- We have worked closely together over the years. Michigan provided one of your presidents, Charles Odegaard, while Washington has provided several of our leading faculty and executives, including most recently Gil Omenn, our Executive Vice President for Medical Affairs.
- We have also shared other skills and perspectives. For example, the University of Washington taught Michigan how to do the stadium "wave" in the 1970s, and in return, Michigan sent a team of administrators to Seattle in the 1980s to teach you how to cope with state budget cuts. Last fall I visited UW to explain the path Michigan has taken over the past couple of decades to become a "privately-financed public university".

But this evening I'm not going to talk about the financial challenges facing our two institutions. I will also avoid the matter of college sports (although I might note that the first meeting set up for this week's visit was with your athletic director, Barbara Hedges, and her coaches to discuss a recent book I have written on this subject). Instead I will concern myself with the impact that shifting federal priorities for scientific research could have on the University of Washington and University of Michigan as two of this nation's leading research universities. In a sense I will speculate how the science policies shaped by Professor Wolfle 50 years ago might evolve in the century ahead.

The character of today's research university was set out some fifty years ago in the seminal report, *Science, the Endless Frontier,* produced by a World War II study group chaired by Vannevar Bush. The central theme of the document was that the nation's health, economy, and military security required continual deployment of new scientific knowledge and that the federal government was obligated to ensure basic scientific progress and the production of trained personnel in the national interest. It insisted that federal patronage was essential for the advancement of knowledge. It stressed a corollary principle—that the government had to preserve "freedom of inquiry," to recognize that scientific progress results from the "free play of free intellects, working on subjects of their own choice, in the manner dictated by their curiosity for explanation of the unknown."[1]

Since the federal government recognized that it did not have the capacity to manage effectively either the research universities or their research activities, the relationship became essentially a *partnership*, in which the government provided relatively unrestricted grants to support part of the research on campus, with the hope that "wonderful things would happen." And, indeed they did, as evidenced by the quality and impact of academic research.

The resulting partnership between the federal government and the nation's universities has had an extraordinary impact. Federally supported academic research programs on the campuses have greatly strengthened the scientific prestige and performance of American research universities. The research produced on our campuses has had great impact on society. This academic research enterprise has played a critical role in the conduct of more applied, mission-focused research in a host of areas including health care, agriculture, national defense, and economic development. It has made America the world's leading source of fundamental scientific knowledge. It has produced the well-trained scientists, engineers, and other professionals capable of applying this new knowledge. And it has laid the technological foundations of entirely new industries such as electronics and biotechnology.

Yet, despite the obvious success of this research partnership, as we enter the new millennium, there is an increasing sense that the social contract between the research university and American society may need to be reconsidered and perhaps even renegotiated once again.[2] The university's multiple stakeholders have expanded and diversified in both number and interest, drifting apart without adequate means to communicate and reach agreement on priorities. Higher education must compete with an increasingly complex and compelling array of other social priorities for limited public funding. Both the public and its elected leaders today view the market as a more effective determinant of social investment than government policy. Perhaps most significant of all, the educational needs of our increasingly knowledge-intensive society are both changing and intensifying rapidly, and this will require a rethinking of appropriate character and role of higher education in the 21st Century.

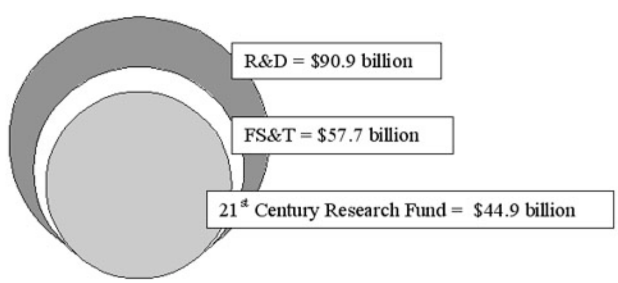
. My perspective of this topic is provided in part by two studies I currently chair for the National Academy of Sciences: 1) a steering group of the NAS Committee on Science, Engineering, and Public Policy (COSEPUP) that each year analyzes and identifies trends in the federal science and technology budget, and 2) a NAS committee concerned with the impact of rapidly evolving information technology on the future of the research university. This is also a very timely topic, since yesterday the new administration released their first budget request for FY2002, and the COSEPUP steering group is already frantically at work analyzing the numbers to identify trends–and concerns. Furthermore, earlier this January our NAS committee concerned with IT and research universities hosted a major workshop at the National Academy of Sciences drawing together over 100 leaders from the IT industry, higher education, and the federal government to discuss the impact of digital technology on the university.

In my brief remarks this morning, I will begin by summarizing several of the early conclusions from each of these studies. I will then relate these to several broader issues concerning national priorities. Finally I will speculate a bit about the future evolution of American science policy and how it could impact universities such as Washington and Michigan.

The COSEPUP Subcommittee on the FS&T Budget

In 1995, the National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council issued a report entitled, *Allocating Federal Funds for Science and Technology*,[3] aimed at making the research funding process more coherent, systematic, and comprehensive; ensuring that funds were allocated to the best people and the best projects; ensuring that sound scientific and technical advice guided the allocation process; and improving the federal management of R&D activities.

This report recommended the use of an alternative to the federal “R&D” budget category that more accurately measured spending on the generation of new knowledge: The *Federal Science and Technology* (FS&T) budget was designed to reflect the true federal investment in the creation of new knowledge and technologies by excluding activities such as hardware procurement and the testing and evaluation of new weapons systems. More specifically, the FS&T budget includes: I) the civilian and non-civilian research budgets for all agencies (including the “6.1” and “6.2” functions at DOD); the development budgets for all agencies except DOD and DOE (for these, only DOD 6.3 and the equivalent activities of the DOE atomic energy defense program are included); and R&D facilities and major capital equipment budgets for R&D. For example, in FY01, although the federal R&D budget recommended by the administration was $90.9 B, only $57.7 B was identified as the FS&T component. In recent years the Clinton administration moved toward a similar budget concept known as the 21st Century Research Fund that stressed its own research priorities.



FY 2001 R&D, FS&T, and 21st Century Research Fund (in billions)

The NAS report also recommended an interesting principle for allocating federal research funding:

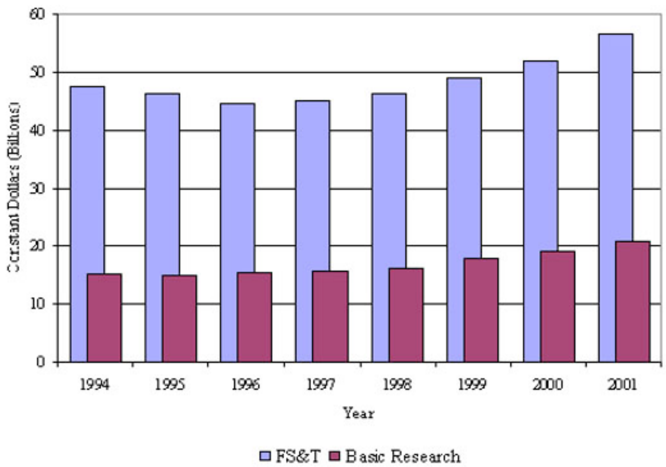
1. The United States should be among the leaders in all major fields of science and technology.
2. The United States should be the absolute leader in key science and technology areas of major strategic importance.

For example, it is clear that the nation should be the absolute leader in areas of strategic importance such as biotechnology, nanotechnology, and information technology. However it need only be among the leaders in an area like high energy physics (implying, of course, that the United States should be prepared to build expensive accelerators through international alliances rather than alone as in the ill-fated Superconducting Supercollider).

To implement these recommendations, the National Academies Committee on Science, Education, and Public Policy (COSEPUP) has first developed a methodology to perform international benchmarking to determine the status of national leadership in various disciplines (e.g., materials science, mathematics, immunology). It has worked closely with the federal government to include benchmarking in the application of the Government Performance Results Act (GPRA) to the research programs of federal agencies. And for each of the past three years, a COSEPUP subcommittee, which I chair, has tracked the administration's R&D budget recommendations from the FS&T perspective. We are preparing to perform this analysis once again for the FY2002 budget request submitted by the Bush administration.

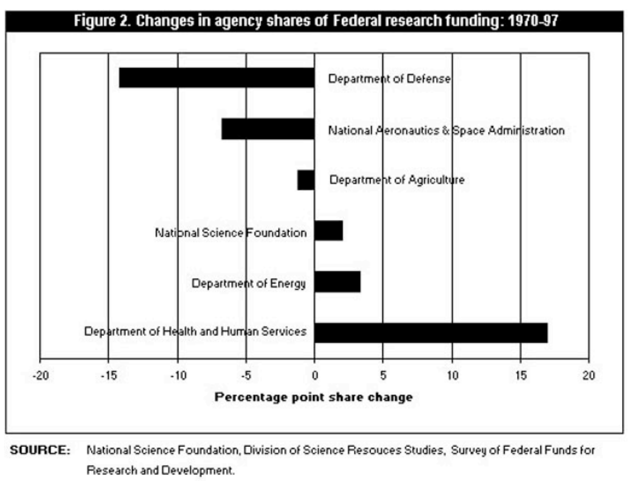
The FS&T analysis has identified a number of interesting trends in federal research support:

1. The FS&T budget dropped significantly in early 1990s and has only recovered in past two years.



FS&T Budget and Basic Research, FY 1994–FY 2001
(budget authority in billions of constant FY 2000 dollars)

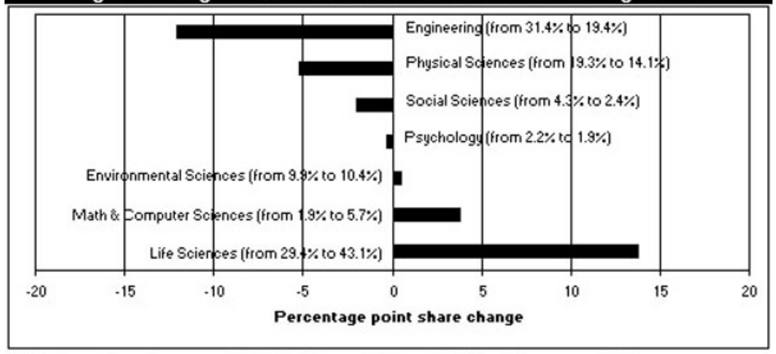
2. During the 1990s, the big winner in federal research appropriations has been the National Institutes of Health (the biomedical sciences); NSF has held its own with modest gains; most mission agencies have lost ground.



More specifically, during the past eight years, the R&D increases experienced by the federal agencies amount to +111% for NIH, +68% for NSF, + 21% for NASA, + 11% for DOD, and –1% for DOE. As a result, today almost 60 cents of every federal research dollar spent on university campuses is for biomedical research.

3. Since scientific disciplines are supported by different federal agencies, a serious imbalance has developed in federal funding among the physical sciences, engineering, social sciences, and life sciences.

Figure 1. Changes in field shares of total Federal research funding: 1970-97

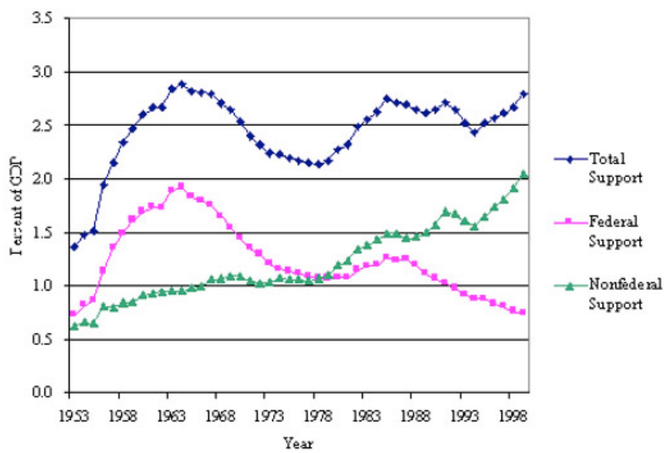


NOTE: Other sciences not classified within one of the broad fields listed above are excluded.

SOURCE: National Science Foundation, Division of Science Resouces Studies, Survey of Federal Funds for Research and Development.

For example, DOD supports 60% of computer science, 69% of electrical and mechanical engineering, 27% of mathematics, and 38% of materials research, so when DOD R&D budgets are cut, these disciplines suffer.

4. The federal government's share of R&D has fallen far below that of industry, dropping from 65% in 1970 to 26% in 1999.[4]



Federal, Non-Federal, and Total Support for R&D as a Percent of GDP

There is a wide consensus that U.S. scientific preeminence and economic growth depend on maintaining the share of GDP devoted to R&D, with a target goal of 3%. And, indeed, total R&D spending has been increasing over the past decade, rising to 2.8% in 2000. Yet since 1987, industry R&D has increased by 196% while the federal share of total R&D has dropped from 46% to 27%. In part this remarkable growth in private sector R&D has been stimulated by the importance of applied research and development in a technology-driven economy. But it also depends on the flow of basic research findings and the associated training of scientists and engineers, principally the concern of the federal government. Hence the growth of industry spending on R&D should not lull observers into thinking that the federal FS&T budget can be reduced. In fact, one might well question whether the current federal investment is adequate to sustain the necessary private sector investment in these activities, so critical to our economic prosperity. Furthermore, a continuing need exists to address possible imbalances among the fields of science and engineering – at a time when many fields are increasingly interdependent for achieving optimal results in the productivity of the economy and the pursuit of knowledge.

These statistics raise the obvious question: How are federal research priorities really determined? One might attribute the pronounced shift in federal science policy from the support of the physical science and engineering to the support of the biomedical sciences as a reflection of changing national priorities over the past 50 years, as the urgency of military security declined with the end of the Cold War, and the concerns about health care grew with the aging of the baby boomer generation. More cynically, one might also consider this shift due in part to the sausage-making process used to construct the federal budget, a process that relies on a Congressional committee structure strongly favoring biomedical research and particularly susceptible to lobbying influence, while penalizing many other science and engineering disciplines by embedding their support in mission agencies subject to appropriations cuts (e.g., DOD and DOE).

Whatever the reason, it is clear that the past 50 years of federal science policy can be captured with the simple phrase: *From guns to pills*…with the pronounced shift in federal priorities for research funding from the support of the physical sciences and engineering to the support of the biomedical sciences.

So much for the past. What might we expect for the next several decades? This brings me naturally to my next topic.

The NAS Committee on the Impact of Information Technology on the Future of the Research University

As a primary source of basic research and the next generation of scholars and professionals, the research university is an institution of great value. In an age in which knowledge and educated people become a society's most valuable resources, the research university has become ever more important as an intellectual force in our society. Today the research faculties in these institutions have become both the leaders and the arbiters of science and scholarship for the world. This group not only leads in knowledge production and distribution, but they have become the gatekeepers and standard-bearers, leading a complex knowledge system that both drives and sustains the global education and learning enterprise. Furthermore, as highly educated scholars and professionals are increasingly sought as leaders in a knowledge-driven world, these institutions should continue to play a critical role. Yet the broader higher education enterprise is changing rapidly–driven by changing social needs, powerful market forces, and rapidly evolving technology–to serve a changing world.

The National Academies (i.e., the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine) have a unique mandate to monitor and sustain the health of the nation's research universities as key elements of the national research enterprise and as critical sources of scientists and engineers. This role becomes particularly important during periods of rapid change. It was in this role that last year the presidents of the National Academies launched a project to understand better the implications of information technology for the future of the research university.[5]

The premise of the National Academies study is a simple one: The rapid evolution of digital technology will present many challenges and opportunities to higher education in general and the research university in particular. Yet there is a sense that many of the most significant issues are neither well recognized nor understood either by leaders of our universities or those who support and depend upon their activities.

The first phase of the project, organized under the Government-University-Industry Research Roundtable (GUIRR), was aimed at addressing three sets of issues:

1. To identify those technologies likely to evolve in the near term (a decade or less) which could have major impact on the research university.

2. To examine the possible implications of these technology scenarios for the research university: its activities (teaching, research, service, outreach); its organization, structure, management, and financing; and the impact on the broader higher education enterprise and the environment in which it functions.

3. To determine what role, if any, there is for the federal government and other stakeholders in the development of policies, programs, and investments to protect the valuable role and contributions of the university during this period of change.

To this end, a Steering Committee to guide the project was formed last year consisting of leaders drawn from industry, higher education, and government with expertise in the areas of information technology, research universities, and public policy. Since first convening in February 2000, the Steering Committee has held several meetings (including site visits to major technology development centers such as Lucent (Bell) Laboratories and IBM Research Laboratories) and held numerous conference calls to identify and discuss trends, issues, and possible recommendations. The key themes addressed by these discussions were:

- The pace of evolution of information technology (e.g., Moore's Law).
- The ubiquitous/pervasive character of the Internet (e.g., wireless, photonics).
- The relaxation (or obliteration) of the conventional constraints of space, time, and monopoly.
- The democratizing character of IT (access to information, education, research).
- The changing ways we handle digital data, information, and knowledge.
- The growing importance of intellectual capital relative to physical or financial capital.

In January 2001 a two-day workshop was held at the National Academies with invited participation of roughly 100 leaders from technology, higher education, and government. The purpose of the workshop was to stimulate a conversation aimed at identifying key themes and issues, to suggest possible recommendations and strategies for research universities and their various stakeholders, and to provide guidance on the next phase of the project. The key presentations and discussion of the workshop were videotaped and broadcast on the Research Channel earlier this year and are currently being video-streamed from its website to serve as an archive for further discussion.

Although the project is still in an early phase, there are already some important preliminary conclusions:

1. The extraordinary evolutionary pace of information technology will not only continue for the next several decades, but it could well accelerate on a superexponential slope. Photonic technology is evolving at twice the rate of silicon chip technology (e.g., Moore's Law), with miniaturization and wireless technology moving even faster, implying that the rate of growth of network appliances will be incredible. For planning purposes, we can assume that within the decade we will have infinite bandwidth and infinite processing power (at least compared to current capabilities).

   For the first several decades of the information age, the evolution of hardware technology followed the trajectory predicted by "Moore's Law"—a 1965 observation/prediction by Intel founder Gordon Moore that the chip density and consequent computing power for a given price doubles every eighteen months.[6] Although this was intended to describe the evolution of silicon-based microprocessors, it turns out that almost every aspect of digital technology has doubled in power roughly every 12 to 18 months, with some technologies such as optical computing, telecommunications, and wireless technology increasing even more rapidly. Put another way, digital technology is characterized by the extraordinary pace of evolution in which characteristics such computing speed, memory, and network transmission speeds for a given price increase by a factor of 100 to 1000 every decade. Furthermore, the technology becomes ever smaller and ever more connected together.

   To be sure, computer technologists are notoriously poor at predictions (as the famous 1950s suggestion by the IBM CEO that the world would never need more than a few computers). But even today digital technology has reached some formidable goals. For example, the information density on hard drives is doubling every year. By way of calibration it is currently possible to put a gigabyte of data on a disk the size of a quarter. New displays are capable of 9 megapixel resolutions, which is noticeably better than paper, and next generation interfaces could use lasers to paint images directly on the retina (as developed by UW's own Tom Furness and his colleagues in UW's Human Interface Technology Laboratory). Bandwidth is continuing to increase rapidly, with 100 Mb/s local area network access routine and 10 Gb/s network backbones common. Software algorithm development is also moving ahead at a pace even faster than Moore's Law. Applications software is advancing rapidly, stimulated by new software paradigms such as genetic algorithms and new forms of collaboration such as open source development (e.g., Linux).

By next year over 90% of homes and 98% of schools in the United States will be connected to the Internet. It is estimated that there will be over 1.5 billion net-enabled cellular phones or PDAs ("personal digital appliances" such as the Palm Pilot) by 2004. Already the Internet links together hundreds of millions of people, and estimates are that within a few years, this number will surge to billions, a substantial fraction of the world's population, driven in part by the fact that most economic activity will be based on digital communication. Bell Laboratories suggests that within two decades a "global communications skin" will have evolved, linking together billions of computers that handle the routine tasks of our society, from driving our cars to watering our lawns to maintaining our health.

Put another way, over the next decade, we will evolve from "giga" technology (in terms of computer operations per second, storage, or data transmission rates) to "peta" technology (one million-billion or 10^{15})[7]. We will denominate the number of computer servers in the billions, digital sensors in the tens of billions, and software agents in the trillions. The number of people linked together by digital technology will grow from millions to billions. We will evolve from "e-commerce" and "e-government" and "e-learning" to "e-everything"!

To illustrate with an extreme example, if information technology continues to evolve at its present rate, by the year 2020, the thousand-dollar notebook computer will have a computing speed of 1 million gigahertz, a memory of thousands of terabits, and linkages to networks at data transmission speeds of gigabits per second. Put another way, it will have a data processing and memory capacity roughly comparable to the human brain.[8] Except it will be so tiny as to be almost invisible, and it will communicate with billions of other computers through wireless technology.

2. The event horizons are moving ever closer. Getting people to think about the implications of accelerating technology learning curves as well as technology cost-performance curves is very important. There are likely to be major technology surprises, comparable in significance to the PC in 1980 and the Internet browser in 1994, but at more frequent intervals. The future is becoming less certain.

3. The impact of information technology on the university will likely be *profound, rapid, and discontinuous*–just as it has been and will continue to be for the economy, our society, and our social institutions (e.g., corporations, governments, and learning institutions). It will affect our activities (teaching, research, outreach), our organizations (academic structure, faculty culture, financing and management), and the broader higher education enterprise as it evolves into a global knowledge and learning industry.

4. For at least the near term, meaning a decade or less, the research university will continue to exist in much its present form, although meeting the challenge of emerging competitors in the marketplace will demand significant changes in how we teach, how we conduct scholarship, and how our institutions are financed. Universities must anticipate these forces, develop appropriate strategies, and make adequate investments if they are to prosper during this period.

5. Over the longer term, the basic character and structure of the research university may be challenged by the IT-driven forces of aggregation (e.g., new alliances, restructuring of the academic marketplace into a global learning and knowledge industry) and disaggregation (e.g., restructuring of the academic disciplines, detachment of faculty and students from particular universities, decoupling of research and education).

6. Procrastination and inaction are the most dangerous courses for colleges and universities during a time of rapid technological change. To be sure, there are certain ancient values and traditions of the university that should be maintained and protected, such as academic freedom, a rational spirit of inquiry, and liberal learning. But, just as in earlier times, the university will have to transform itself to

serve a radically changing world if it is to sustain these important values and roles.

7. Although we feel confident that information technology will continue its rapid evolution for the foreseeable future, it is far more difficult to predict the impact of this technology on human behavior and upon social institutions such as the university. It is important that higher education develop mechanisms to sense the changes that are being driven by information technology and to understand where these forces may drive the university.

8. Because of the profound yet unpredictable impact of this technology, it is important that institutional strategies include : 1) the opportunity for experimentation, 2) the formation of alliances both with other academic institutions as well as with for-profit and government organizations, and 3) the development of sufficient in-house expertise among the faculty and staff to track technological trends and assess various courses of action.

9. In summary, for the near term (meaning a decade or less), we anticipate that information technology will drive comprehensible if rapid, profound, and discontinuous change in the university. For the longer term (two decades and beyond), all bets are off. The implications of a million-fold increase in the power of information technology are difficult to even imagine, much less predict.

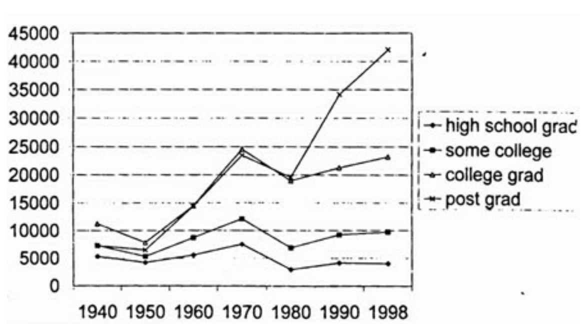
This second phase of the National Academy project will include a number of further activities: 1) the formation of an ongoing roundtable group consisting of leaders from higher education, industry, and government to monitor and assess the implications of evolving technology; 2) the conduct of campus-based discussions among faculty and administrators on a number of university campuses (similar to the "Stresses on the Academy" study jointly conducted by the National Academies and the National Science Board during the 1990s); 3) leadership development conferences drawing together key constituencies both from the campuses (e.g., university administrators, faculty leadership, trustees) and from the stakeholders of the research university (e.g., government agencies, foundations, scholarly societies); and 4) the launch of a series of more focused research projects and technology demonstration efforts designed to raise awareness and assist institutions in developing appropriate strategies. These activities will be supported through the development of web-based resources such as web portals and knowledge environments that are intended to be maintained and serve for the next several years as resources for the higher education community and its stakeholders.

The ultimate goal of the National Academies project is to assist research universities and their various stakeholders in responding to the challenges and opportunities presented by digital technology in such a way that strengthen and enhance those roles so important to the future of our nation and our world.

Several Other Data Points

Ask any governor about state priorities these days and you are likely to hear concerns expressed about education and workforce training. The skills race of the 21st Century knowledge economy has become comparable to the space race of the 1960s in capturing the attention of the nation. Seventy percent of Fortune 1000 CEOs cite the ability to attract and retain adequately skilled employees as the major issue for revenue growth and competitiveness. Corporate leaders now estimate that the high performance workplace will require a culture of continuous learning in which as much as 20% of a worker's time will be spent in formal education to upgrade knowledge and skills. Tom Peters suggests that the 21st Century will be known as the "Age of the Great War for Talent", since in the knowledge economy, talent equates to wealth.[9]

The signs of the knowledge economy are numerous. The pay gap between high school and college graduates continues to widen, doubling from a 50% premium in 1980 to 111% today. Not so well know is an even larger earnings gap between baccalaureate degree holders and those with graduate degrees.



The earning gap between various degree levels

The market recognizes this growing importance of intellectual capital, as evidenced by a comparison of the market-capitalization per employee of three companies:

General Motors	$141,682
Walt Disney Company	$743,530
Yahoo	$33 million

In fact, the market-cap-per-employee of the top 10 Internet companies averages $38 million! Why? In the knowledge economy, the key asset driving corporate value is no longer physical capital or unskilled labor. Instead it is intellectual and human capital.

Today we are evolving rapidly—decade by decade, year by year—into a post-industrial, knowledge-based society, a shift in culture and technology as profound as the transformation that took place a century ago as an agrarian America evolved into an industrial nation.[10] Industrial production is steadily shifting from material- and labor-intensive products and processes to knowledge-intensive products. A radically new system for creating wealth has evolved that depends upon the creation and application of new knowledge.

In a very real sense, we are entering a new age, an *age of knowledge*, in which the key strategic resource necessary for prosperity has become knowledge itself, that is, educated people and their ideas.[11] Unlike natural resources such iron and oil that have driven earlier economic transformations, knowledge is inexhaustible. The more it is used, the more it multiplies and expands. But knowledge is not available to all. It can be absorbed and applied only by the educated mind. Hence as our society becomes ever more knowledge-intensive, it becomes ever more dependent upon those social institutions such as the university that create knowledge, that educate people, and that provide them with knowledge and learning resources throughout their lives.

But here we face a major challenge, since it is increasingly clear that we are simply not providing our citizens with the learning opportunities needed for a 21st Century knowledge economy. Recent TIMMS[12] scores suggest that despite school reform efforts of the past two decades, the United States continues to lag other nations in the mathematics and science skills of our students. Despite the growing correlation between the level of one's education and earning capacity, only 21% of those in our population over the age of 25 have graduated from college. Furthermore, enrollments in graduate programs have held constant or declined (particularly in technical fields such as engineering and computer science) over the past two decades.[13]

The space race galvanized public concern and concentrated national attention on educating “the best and brightest,” the elite of our society. The skills race of the 21st Century will value instead the skills and knowledge of our entire workforce as a key to economic prosperity, national security, and social well-being. We can well make the case that it has become the responsibility of democratic societies to provide their citizens with the education and training they need throughout their lives, whenever, wherever, and however they desire it, at high quality and at a cost they can afford. Yet there is growing concern about whether our existing institutions have the capacity to serve these changing and growing social needs—indeed, even whether they will be able to survive in the face of the extraordinary changes occurring in our world.

Both young, digital-media savvy students and adult learners will likely demand a major shift in educational methods, away from passive classroom courses packaged into well-defined degree programs, and toward interactive, collaborative learning experiences, provided when and where the student needs the knowledge and skills. The increased blurring of the various stages of learning throughout one’s lifetime–K-12, undergraduate, graduate, professional, job training, career shifting, lifelong enrichment–will require a far greater coordination and perhaps even a merger of various elements of our national educational infrastructure.

The growing and changing nature of the educational needs of our society will trigger strong economic forces. Already, traditional sources of public support for higher education such as state appropriations or federal support for student financial aid have simply not kept pace with the growing demand. This imbalance between demand and available resources is aggravated by the increasing costs of education, driven as they are by the knowledge- and people-intensive nature of the enterprise as well as by the difficulty educational institutions have in containing costs and increasing productivity. It also stimulated the entry of new for-profit competitors into the education marketplace.

The Federal Role in Meeting the Nation’s Need for Intellectual Capital

As the United States enters a new century, we face social and economic challenges triggered by globalization, technological change, and demographic change that have established the development of our nation’s human and intellectual capital as our highest domestic priority. At similar critical periods in our nation’s history, the federal government took strong action to address our citizens’ needs for education. The

Northwest Ordinances of 1785 and 1787 established the principle of government support of schools by setting aside public lands to support public schools in each new state. The Morrill Act of 1862 and the other Land-Grant Acts democratized higher education, transforming it from a privilege of the elite to an opportunity for the working class, while stimulating the development of academic programs in applied areas such as agriculture and engineering to serve an industrial economy. The 1944 GI Bill provided millions of returning veterans with the opportunity for a college education. The Truman Commission of 1948 stated its belief that every high school graduate should have the opportunity for a college education and laid the foundation for the sequence of federal student loan programs which has made this dream possible for a significant fraction of our population. The concern for national security stimulated a research partnership between the federal government and our universities that led to strong support of graduate education and research on our campuses.

Hence there are strong precedents for federal policies, programs, and investments that work through our colleges and universities to address national priorities. What might we expect in the decades ahead?

Federal R&D in the “Science of Education”

We have argued that the development of human capital is becoming a dominant national priority in the age of knowledge, comparable in importance to military security and health care. Yet our federal investment in the knowledge base necessary to address this need in miniscule. In FY01, the nation will invest over $247 billion in R&D. Of the federal government’s share of $90 billion, $20.4 billion will be invested in NIH, $8 billion in space, $4.4 billion in NSF, and $2 billion in high energy physics. How much will the federal government invest in research directed toward learning, education, and schools? Less than $300 million–about 0.2% of our investment in the biosciences or 1% of that in high energy physics. Of this amount, only about $50 million is currently invested in the underlying basic science of learning (e.g., neuroscience, cognitive science, organizational science related to learning).

To view this paltry investment from a somewhat different perspective, most industries spend between 3% to 10% per year of revenues for R&D activities. By this measure, the education sector of our economy (including K-12, higher education, and workforce training), which amounts to $665 billion, should be investing $20 billion or greater each year in R&D, roughly the same order of magnitude as the health care sector. Yet currently only about 0.3% of public spending on children and education is devoted to R&D. Evidence from other domestic areas in crisis that are primarily public-sector responsibilities suggest that inadequate investment in R&D is a key factor resulting in inadequate innovation and adoption in new technology. If the public sector is unwilling to invest in R&D where it bears prime responsibility, perhaps it is not surprising that progress in education and improving learning outcomes for our children has been slow and uncertain.

Of course, one might raise the question of how we define R&D in education. It is not my intent to wade into the swamp of discussing whether the bulk of the activity supported by the Department of Education, such as the office of Educational Research and Improvement, is actually "research," at least in the sense that most other scientists would understand it.[14] Nor will I address the growing investments of for-profit competitors such as Unext.com and the University of Phoenix in the development of educational products or assessment tools.

Rather I would like to focus my discussion on what many term the "science of learning," meaning research that would be classified by scientists as guided by the scientific method and subject to rigorous review by the scientific community. Included in this would be research in areas such as neuroscience, cognitive psychology, organizational theory, and the quantitative social and behavioral sciences. New opportunities for breakthroughs in understanding children's cognitive development are emerging in brain research. A strong scientific infrastructure could be developed to link basic brain research with more applied areas of cognitive, emotional, physical, and social development, similar to that which occurred in the understanding of solid state physics necessary for microelectronics or the science of genomics and cellular biology important for modern medicine.

There are similar opportunities in systemic areas such as the design of learning systems. For example, how would one explore different architectures of learning environments, institutions, and enterprises for an age of knowledge? Here the goal would be to set aside the constraints of existing educational structures (e.g., schools, colleges, workplace training) and practices and begin with a clean slate to consider how one might meet the live long educational needs of citizens in a global knowledge-driven society. How would one design learning experiences, resources, and institutions that exhibit the various characteristics suggested for learning institutions in the 21st Century:

learner-centered, interactive and collaborative, asynchronous and ubiquitous, intelligent and adaptive, lifelong and evolutionary, diverse, and affordable.

Of particular interest here is the redesign of the national learning infrastructure that provides technical knowledge and skills (science, math, technology) and the learning skills necessary for a knowledge-driven society. There also needs to be consideration given to how to design a learning architecture that narrows the digital divide, with a particular concern given to providing educational opportunities to those who have been traditional disadvantaged by our current educational systems.

Although the U.S. Department of Education has traditionally been assigned the responsibility for federal leadership and policy development in education, particularly at the K-12 level, it could be that the most appropriate federal agency for providing national leadership in creating a new learning infrastructure might well be the National Science Foundation. This is suggested by several considerations: 1) Much of the knowledge most critical to our future will be based upon science, mathematics, and technology. 2) The NSF is unique among federal agencies in having both a charter and experience in the conduct of fundamental research concerning education at all levels. 3) The NSF is also unique in its ability to engage the entire research community in high-quality, merit-driven research directed at national priorities such as education. In fact, much of the innovation in life-long learning will be based upon research and development sponsored by NSF in fields such as information technology, cognitive science, and the social and behavioral sciences.

The current Interagency Education Research Initiative provides one interesting approach to rapidly scaling up federal investment in educational research. All federal agencies have human capital needs and therefore some responsibility for investment in education and skills development (much as they have been assigned roles in economic development through the Small Business Initiative Research program). Each could be a participant in a broader interagency program, similar to the strategic Information Technology Research or Nanotechnology Research programs of the past several years, with the National Science Foundation as the lead agency.

Another interesting model for the conduct of research on education and learning is provided by the DOD’s Defense Advanced Research Programs Agency (DARPA). Through a process using strong program managers to channel significant, flexible, and long-term funding to the very best researchers for both basic and applied research undergirding key defense technologies, DARPA has been able to capture contributions of the nation's scientists and engineers in highly innovative projects. Many of today's technologies such as microelectronics, computer science, materials science, and nanotechnology can be traced to earlier DARPA programs. Perhaps we need an *Education Advanced Research Programs Agency* to focus the capabilities of the American research enterprise on what many believe to be our nation's most compelling priority, the quality of education for a knowledge-driven society. Since the Department of Education has so little experience in merit-driven basic research activities and limited credibility with the broader scientific community, other federal agencies such as the NSF and NIH might serve as partners to provide guidance and oversight during the startup phase of an "EARPA". This might also might provide a source of intellectual energy and vitality in the Department of Education, similar to that provided by basic research activities in other mission agencies (DOD, DOE, NASA, etc.). To convince the research community that this is a serious effort and not simply channeling more money into the education establishment, it might even be useful to seek the National Academies participation in such activities.

A third possible approach would be to adopt the model used in health research, which is undergirded by solid basic and applied research based on the use of clinical trials and of ongoing longitudinal studies tracking health behavior and status focusing on virtually every health problem. Health research also has an institutional infrastructure based on teaching hospitals, schools of public health and academic research centers that closely link research to training, practice, and public education. All of this is aided by a central funding agency–the National Institutes of Health–that is guided by scientific peer review and is able to set priorities and achieve more investment in infrastructure. In contrast, most research on education lacks a solid basic research component, with almost no scientifically structured clinical trials, relatively few major longitudinal surveys, and no equivalents of teaching hospitals or schools of public health that combine research with practice. The R&D community is fragmented across disciplines and federal departments that invest in infrastructure, making investment inefficient.

Beyond new mechanisms to stimulate and support research in the science of education, we also need to develop more effective mechanisms to transfer what we have learned into schools, colleges, and universities. For example, the progress made in cognitive psychology and neuroscience during the past decade in the understanding of learning is considerable.[15] Yet almost none of this research has impacted our schools.

As one of my colleagues one said, "If doctors used research like teachers do, they would still be treating patients with leeches."

Of course, there are currently very real constraints imposed by those in the Administration and Congress who have difficulty accepting a more revolutionary educational role for the federal government. Although education is clearly felt to be a priority in our society, it is generally viewed and supported within the constraints of existing perspectives, policies, and programs. It may well be true that many of the current problems plaguing education in America are political, organizational, and economic. But without a firm scientific understanding of how learning actually occurs and how learning environments should be developed, interventions will continue to be ineffective, and progress will be limited.

A Learn-Grant Act for the 21st Century

Recall that a century and a half ago, America was facing a period of similar change, evolving from an agrarian, frontier society into an industrial nation. At that time, a social contract was developed between the federal government, the states, and public colleges and universities designed to assist our young nation in making this transition. The land-grant acts were based upon several commitments: First, the federal government provided federal lands for the support of higher education. Next, the states agreed to create public universities designed to serve both regional and national interests. As the final element, these public or land-grant universities accepted new responsibilities to broaden educational opportunities for the working class while launching new programs in applied areas such as agriculture, engineering, and medicine aimed at serving an industrial society, while committing themselves to public service, engagement, and extension.

As we noted earlier, today our society is undergoing a similarly profound transition, this time from an industrial to a knowledge-based society. Hence it may be time for a new social contract aimed at providing the knowledge and the educated citizens necessary for prosperity, security, and social well-being in this new age. Perhaps it is time for a new federal act, similar to the land grant acts of the nineteenth century, that will help the higher education enterprise address the needs of the 21st Century. Of course, a 21st Century land-grant act is not a new concept.[16] Some have recommended an industrial analog to the agricultural experiment stations of the land-grant universities. Others have suggested that in our information-driven economy, perhaps telecommunications bandwidth is the asset that could be assigned to universities much as federal lands were a century ago. Unfortunately, an industrial extension service may be of marginal utility in a knowledge-driven society. Furthermore, Congress has already given away much of the available bandwidth to traditional broadcasting and telecommunications companies.

But there is a more important difference. The land-grant paradigm of the 19th and 20th Century was focused on developing the vast natural resources of our nation.[17] Today, however, we have come to realize that our most important national resource for the future will be our people. At the dawn of the age of knowledge, one could well make the argument that education itself will replace natural resources or national defense as the priority for the twenty-first century. We might even conjecture that a social contract based on developing and maintaining the abilities and talents of our people to their fullest extent could well transform our schools, colleges, and universities into new forms that would rival the research university in importance. In a sense, the 21st Century analog to the land-grant university might be termed *a learn-grant university*.

A learn-grant university for the 21st Century might be designed to develop our most important asset, our human resources, as its top priority, along with the infrastructure necessary to sustain a knowledge-driven society. The field stations and cooperative extension programs–perhaps now as much in cyberspace as in a physical location–could be directed to the needs and the development of the people in the region. Furthermore, perhaps we should discard the current obsession of research universities to control and profit from intellectual property developed on the campus through research and instruction by wrapping discoveries in layer after layer of bureaucratic regulations defended by armies of lawyers, and instead move to something more akin to the “open source” philosophy used in some areas of software development. That is, in return for strong public support, perhaps public universities could be persuaded to regard all intellectual property developed on the campus through research and intellectual property as in the public domain and encourage their faculty to work closely with commercial interests to enable these knowledge resources to serve society, without direct control or financial benefit to the university. MIT has recently taken a major leadership step in this direction with its “open course learning ware” project, which aims at putting the materials for over 2,000 MIT courses on the web for public use.

In an era of relative prosperity in which education plays such a pivotal role, it may be possible to build the case for new federal commitments based on just such a vision of a society of learning. But certain features seem increasingly apparent. New investments are unlikely to be made within the old paradigms. For example, while the federal government-research university partnership based on merit-based, peer-reviewed grants has been remarkably successful, this remains a system in which only a small number of elite institutions participate and benefit. The theme of a 21st Century *learn-grant act* would be to broaden the base, to build and distribute widely the capacity to contribute both new knowledge and educated knowledge workers to our society, not simply to channel more resources into established institutions.

An interesting variation on this theme is the *Millennium Education Trust Fund* proposed by Lawrence Grossman and Newton Minnow.[18] This fund would be established by investing the revenues from the sale or lease of the digital spectrum and would serve the diverse educational, informational, and cultural needs of American society by enhancing learning opportunities, broadening our knowledge base, supporting the arts and culture the skills that are necessary for the Information Age. Grossman and Minnow estimate that the auctions of unused spectrum over the next several years could yield at least $18 billion. These revenues, placed in a Millennium Education Trust Fund, would work just as the Northwest Ordinance and Morrill Act did in past centuries, investing proceeds from the sale of public property in our nation's most valuable asset, our people,

Whatever the mechanism, the point seems clear. It may be time to consider a new social contract, linking together federal and state investment with higher education and business to serve national and regional needs, much in the spirit of the land-grant acts of the 19th Century.

Concluding Remarks

My remarks today have been based on three fundamental premises:

1. We have entered an age of knowledge in which educated people and their ideas have become the keys to economic prosperity, national security, and social well-being. Furthermore in such an age, education has become the key determinant of one's personal prosperity and quality of life.

2. It has become the responsibility of democratic societies to provide all of their citizens with the education and training they need, throughout their lives, whenever, wherever, and however they desire it, at high quality, and at an affordable cost; that is, to create a "society of learning" in which life-long educational opportunities become not only available but pervasive in the lives of all of our citizens.

3. Although the major investments in the learning infrastructure necessary to create and sustain a society of learning will come from the private sector and local government at the state and community level, leadership, research, and the development of a policy framework are the responsibility of the federal government.

These are challenging issues, to be sure. But just as the space race of the 1960s stimulated major investments in research and education, there are early signs that the skills race of the 21st Century may soon be recognized as the dominant domestic policy issue facing our nation, thereby providing an opportunity not simply for new investments but as well allowing us to break free of existing constraints and evolve toward a society of learning.

If the past 50 years of science policy can be characterized as a transition in national priorities "from guns to pills," let me suggest that the next 50 years will see the transition "from pills to brains". It is time that we realized that our nation's intellectual capital, the education of our people, the support of their ideas, their creativity, and their innovation, will become the dominant priority of a knowledge-driven nation.

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[1] Vannevar Bush, *Science, the Endless Frontier*, a report to the President on a Program for Postwar Scientific Research (Office of Scientific Research and Development, July 1945; Washington, D.C.: National Science Foundation, 1990), 192.

[2] Vernon Ehlers, "Unlocking Our Future: Toward a New National Science Policy," a report to Congress by the House Committee on Science (September 24, 1998).

[3] *Allocating Federal Funds for Science and Technology,* Committee on Criteria for Federal Support of Research and Development, (National Academy Press, Washington, 1995).

[4] Federal R&D as a percentage of total R&D in the US reached a high point in 1964 at 66.8 percent, equaled 46.4% in 1987, and in 1999 was 26.7 percent. See NSF, *National Patterns of Research and Development Resources 1999 Data Update* (NSF 00-306).

[5] The co-principal investigators of the National Academies project are William A. Wulf, President of the National Academy of Engineering and Professor of Computer Science at the University of Virginia and James J. Duderstadt, Professor of Science and Engineering at the University of Michigan. Raymond E. Fornes, Associate Vice President for Research at North Carolina State University, has served as the senior Academy staff member for the project.

[6] Peter J. Deming and Robert M. Metcalf, *Beyond Calculation: The New Fifty Years of Computing* (New York: Springer-Verlag, 1997).

[7] Put another way, a petabyte of data is roughly equivalent to the capacity of a stack of CD-ROMs nearly 2 km high.

[8] Ray Kurzweil, *The Age of Spiritual Machines: When Computers Exceed Human Intelligence* (New York: Viking, 1999).

[9] Michael Moe, *The Knowledge Web: People Power– Fuel for the New Economy* (Merrill-Lynch, New York, 2000)

[10] Peter F. Drucker, "The Age of Social Transformation," *Atlantic Monthly,* November 1994, 53–80; Peter F. Drucker, *Post-capitalist Society* (New York: Harper Collins, 1993).

[11] Erich Bloch, National Science Foundation, testimony to Congress, 1988.

[12] *The Third International Mathematics and Science Study-Repeat*, National Science Foundation and Department of Education, 2001.

[13] Douglas S. Massey, "Higher Education and Social Mobility in the United States 1940-1998 (Association of American Universities, Washington, 2000)

[14] Maris Vinovskis, "The Federal Role in Educational Research and Development," Brookings Papers on Education Policy 2000 (The Brookings Institution, Washington, 2000) pp. 359-380.

[15] *How People Learn: Brain, Mind, Experience, and School*, The Committee on Developments in the Science of Learning, National Research Council (National Academy Press, Washington, 2000)

[16] *Renewing the Covenant: Learning, Discovery and Engagement in a New Age and Different World*, Kellogg Commission on the Future of the State and Land-Grant Universities (2000); Walter E. Massey, "The Public University for the Twenty-First Century: Beyond the Land Grant," 16th David Dodds Henry Lecture, University of Illinois at Chicago, (1994); J. W. Peltason, "Reactionary Thoughts of a Revolutionary," 17th David Dodds Henry lecture, University of Illinois at Urbana-Champaign (October 18, 1995).

[17] Frank Rhodes, "The New American University," *Looking to the Twenty-First Century: Higher Education in Transition* (Champaign-Urbana: University of Illinois Press, 1995).

[18] Lawrence K. Grossman and Newton N. Minow, *A Digital Gift to the Nation: Fulfilling the Promise of the Digital and Internet Age* (Carnegie Corporation of New York, New York, 2000).