A Presentation by

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What's In A Name? Basic vs. Applied vs. Strategic Research

Sigma Xi
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Introduction

Good evening. Once again I have the privilege of joining this distinguished group of colleagues and friends to speak with you at the annual Sigma Xi lecture series about what I believe to be some of the most important issues facing the scientific community today—including the future of our nation's basic research capability.

As I have done in past years in this, my "annual talk on the state of science in America," I will draw more from my perspective as chair of the National Science Board (NSB) than as president of the University.

Some Signs of the Times

There are many reasons for concern today, including:

- the crash of big science
- the Hubble Space Telescope
- the Mars Observer
- the collapse of the Superconducting Supercollider (SSC) project
- the controversy over LIGO, Gemini

Science and Engineering Indicators

Compared to other nations, the U.S. still maintains the largest investment in total R&D and industrial R&D. However other countries are either closing the gap or even lead the U.S. by some measures. The real rate of growth in U.S. industrial R&D has been declining since the late 1970s and early 1980s. Our national investment in non-defense R&D continues to lag behind that of other nations. While academia continues to increase its share of national R&D, the federal funding fraction of this has been declining since 1980, with contributions from the universities themselves increasing.

International comparisons between the highest achieving nations and the U.S. continue to show lagging U.S. performance, even when comparing our best school districts.

The absolute number of undergraduate degrees in engineering, mathematics, and computer science continues to decline.

Mission Agencies

NASA is rapidly reducing fundamental space science in favor of mission projects, e.g., priorities are indicated as Mission to Planet Earth and Space Station. Most basic science will increasingly be conducted in support of these missions.

The Department of Energy seems to be focusing more on correcting the sins of the past—radioactive waste, dismantling nuclear weapons, and human experiments with radioactivity—than looking toward the future.

And, of course, the Department of Defense is downsizing rapidly. With "defense conversion," basic research (6.1 projects) is usually the first casualty.

Congressional Potshots

Congressional interest in science and technology policy remains very high. There is some good news. The National Science Foundation (NSF) budget for FY94 is up 11 percent, and the National Institutes for Health (NIH) budget is up 5.2 percent. Yet there has been a shift in focus.

George E. Brown has said, "A more precise model of the role of research in our culture might portray applied R&D as sources of the technological innovations that fuel economic growth, ease the struggle for survival, and free increasing numbers of human beings to pursue self-realization through the endeavors of the intellect and spirit."

Senator Barbara Mikulski, in the Senate Appropriation Committee Report Language, requested that "not less than 60 percent of the agency's annual program research activities should be strategic in nature. The Foundation should make clear how it specifically defines each area so as not to shroud curiosity-driven activities

under the rubric of strategic activities. The NSF and the Science Board should outline a plan for increasing the scientific community's understanding of the vital need for this balance to exist."

Senator Mikulski added, "It is time for the NSF to move to identify that which is specific, immediate, and realizable. If the NSF and its constituent members choose not to do this, future federal R&D budgets should instead be allocated more generously to mission agencies."

The Stresses on Universities

During the course of the past year, I have been involved in an effort sponsored by the National Science Board to understand better the stresses on the academy as seen from the perspectives both of the faculty and university administrations. It is clear from a number of forums we have hosted on university campuses across the nation that there is a growing gulf between those characteristics faculty value—such as an emphasis on basic research; a highly disciplinary focus; and strong, long-term support for individual investigators—and the terms dictated by federal and industrial sponsors, e.g., more applied investigations of a highly interdisciplinary nature involving large research teams.

Put another way, the faculty believes they are deprived of the opportunity to do what they do best—thinking, dreaming, talking, teaching, and writing—by the pressures of the day which force them to hustle contract research, manage research projects, and deal with government and university bureaucrats, all of which takes them out of not only the classroom but the laboratory as well.

While the stress on the faculty today has many symptoms, it has fundamentally one major cause: the stress associated with the reaction to change—change which is occurring far more rapidly in universities than most of us can adapt to comfortably.

Indeed, one member of our study group remarked that university faculties appear to be the last groups remaining in our society who believe that "the status quo is still an option"!

Mary Good, Deputy Secretary of Commerce and former Chair of the National Science Board, has said:

> "Whether we like it or not, the end of the Cold War has transformed the research community from a relatively intimate one in which government was the main customer—and technology was sought at any price—to a much broader one where industry is the main customer and the price is paramount.
>
> "This fundamental change in end-user of research is being paralleled by a 'cultural change' in which the university is still thinking in terms of 'educating' people, but the public really thinks in terms of 'training' people.
>
> "It is a different viewpoint. The public doesn't tolerate very well all of the high-sounding things if I spend this tuition at $25,000 a year and my kid gets out and can't find a job."

Good called on the universities to exhibit "some statesman leadership" of their own. The universities need to take the lead in talking about these issues as they are, not as we'd like them to be, and beginning to articulate what the real, appropriate role of the university is in today's society. We need to discuss where we wish to be in the twenty-first century, not what our role was in 1950.

Good said that as they move into the future, "universities have to return to the concept of service and to do that they have to understand what the public wants Universities are a service industry, and if the service that you provide over

time does not satisfy the customer—who is the public—then they won't pay. It really is almost that simple."

What Is Really Going On?

Intellectual Change

First, there has been intellectual change. Recall last year's Senate Assembly speech, "Redrawing the Boundaries" and meetings with faculty we have held throughout the year. If there was a single dominant theme of these meetings, it was the faculty's great frustration with degree to which the rigidity of the traditional disciplines constrain their teaching and scholarship. Most faculty believe their work is increasingly interdisciplinary in nature, but that the difficulties in crossing disciplinary boundaries within the University are preventing them from keeping pace with intellectual change.

These same concerns are shared by many others on our campus. For example, in a recent survey conducted of faculty members with interests in environmental issues, 74 percent stated their belief that our present academic climate did not adequately encourage or support interdisciplinary efforts.

John Armstrong, former head of IBM's research labs, has said, "I am persuaded that God did not make the natural world according to the departmental structure of research universities. Nature is not divided up into compartments like a wall of post-office boxes, with physics in this box and chemistry in that. Despite the practical utility of these disciplinary boundaries, they lull us into forgetting that nature is interconnected and complex in ways we still only dimly perceive. Time and time again we have seen how following one thread in nature's web leads to the discovery of an unexpected, seemingly unrelated thread of great scientific and/or technological significance."

We are entering an era in which the boundaries between basic and applied research erode. More than ever before science will drive technology, and technology will accelerate scientific progress. If the boundaries between basic and applied research fade, commercial relevance will be an intrinsic feature if not a state goal of most of science. So, too, for social benefits such as fighting disease or improving the environment.

In his blueprint for American science drafted fifty years ago, Vannevar Bush noted, "The scientist doing basic research may not be at all interested in the practical applications of his work, yet further progress of industrial development would eventually stagnate if basic scientific research were long neglected."

Bush believed that if we just did good curiosity-driven research good things would happen and society would be well-served. Unfortunately, this is no longer accepted by society.

From Guns to Butter

For almost half a century, the driving force behind many of the major investments in our national infrastructure has been the concern for national security in the era of the Cold War.

The evolution of the research university, the national laboratories, the interstate highway system, our telecommunications systems and airports, and the space program—all were stimulated by concerns about the arms race and competing with the Communist Bloc.

So too, much of the technology that we take for granted—from semiconductors to jet aircraft, from computers to composite materials—all were spin-offs of the defense industry. Yet in the wake of the extraordinary events of the last five years—the disintegration of the Soviet Union and Eastern Europe, the reunification of Germany, and the major steps toward peace in the Middle East —the driving force of national security has

disappeared, and along with it, much of the motivation for major public investment.

Far from a "peace dividend" providing new resources in a post-Cold War world for investment in key areas such as education and research, the nation is instead drifting in search of new driving imperatives. While there are numerous societal concerns such as economic competitiveness, national health care, crime, and K-12 education, none of these has yet assumed an urgency sufficient to set new priorities for public investments.

Further, much of the existing intellectual infrastructure, developed to underpin national defense, is now at risk. The national laboratories are facing massive downsizing and necessarily searching for new missions. The burdens of the massive debts incurred in the buyout-merger mania of the late 1980s have forced corporate America to downsize R&D activities, including the shift of many of America's leading corporate research laboratories such as the Bell Laboratories and the IBM Research Laboratories from long-term research to short-term product development.

Equally serious are signs that the nation is no longer willing to invest in research performed by universities, at least at the same level and with a similar willingness to support curiosity-driven basic research. Congress has made it clear that it will insist that universities focus increasingly on applied research, more directly related to national priorities (although many industrial leaders have tried in vain to explain that without "basic" research, there is nothing to "apply").

The federal government has yet to develop an successor to the government-university research partnership which served so well during the Cold War years. So the whole issue of having to interact with the outside world and having to understand some of the needs is really very important. We are entering an era in which the boundaries between basic and applied re-

search erode. Today's more powerful link between scientific leadership, economic security, and quality of life will provide the new impetus and rationale for the support of science in the post-Vannevar Bush Era, just as the valuable military contributions of science gave Bush and his colleagues the standing to launch the current era of federal support of science.

There is also a generational effect facing the scientific community today. Before the creation of the National Science Foundation after the second World War, and during many of the subsequent years, we did not have to spend time justifying our R&D efforts. The nation seemed grateful for the contributions of our scientists.

Today we have many people in positions of power who weren't around at that time. And the general public may not consider the legacy to be that we won the war, but rather that we have to consider the environmental consequences of nuclear explosions, or that we have living among us people who unknowingly participated in radiation experiments.

The Post-Vannevar Bush Era

In the post-Vannevar Bush era numerous reports on these issues have been released, most significantly from the National Science Board (NSB); President's Council of Advisors on Science and Technology (PCAST); Federal Coordinating Council for Science, Engineering and Technology (FCCSET); Government University Industry Research Roundtable (GUIRR); and most recently from the National Academies of Science and Engineering.

As Harold Shapiro noted, science policy is very high on the domestic and international agendas of many nations. This is not the cause of a desire to remain on the scientific frontier, but rather an increased anxiety to put in place public policies that will maximize a nation's continuing capacity to develop and deploy economically competitive technologies in the new international marketplace.

It is being driven by:

- the rapid convergence of incomes, productivity, and the ability to develop and effectively implement new tech nologies
- a more open world economy
- the increasing technological intensity of an ever-wider spectrum of products
- the continued escalation of the pace of discovery
- the rapid development of world-wide "information nets" that allow the quicker dispersion of new knowledge and know-how.

The View from Washington

Shapiro goes on to note that U.S. Science Policy has become a mosaic of policies that is now rather poorly coordinated. It has become increasingly dominated by the many different, largely mission-oriented congressional initiatives. While most accept the view that basic research was an important component of any self-sustaining innovation system, the objectives of U.S. science policy has always been motivated by very practical and rather well-defined pragmatic objectives.

Most observers would agree that despite a high level of federal support for R&D, the current federal investment in R&D is no longer based on any coherent overall policy or strategy.

And what is the current sentiment in Washington? In general, there is a lot of apprehension about the commitment of the Clinton Administration to basic research. You may have also heard the buzz that research universities, or perhaps more accurately higher education, has become just another special interest group, fighting for a piece of the federal budget each year.

Much of the problem is the institutional structure of Congress where most committees and, therefore, budget decisions are organized around specific mission-oriented agencies, e.g., defense, energy, health.

Congressional Anarchy

As I mentioned earlier, in the FY94 appropriations bills, both the NSF and NIH did fairly well, receiving 11 percent and 5.2 percent increases respectively over FY93. Today we find serious consideration being given to shifting the emphasis of federal science policy from such missions as defense, space, and energy to a new set of missions such as economic competitiveness and environmental concerns. More simply put, industry, rather than areas such as space and national security, would become the key focus.

With respect to the NSF, the Senate Appropriations Committee called for NSF and, therefore, the university research community to place increased emphasis on "strategic research."

While the final House-Senate Conference Committee Report did not contain any of the language on the NSF's future, it is clear that this is a call to action. The Senate Appropriations Committee would prefer that the NSF spend at least 60 percent annually on what they refer to as "strategic" research—or else don't expect much new federal money next year.

In these proposals there is an increasing urgency and focus on the short-term and the almost desperate hope that there is some relatively easy way to transform science policy to achieve some early dividend.

And here we come to the place where we could benefit from clarity. What does the phrase "strategic research" mean to you? And what does it mean to the Congress?

One explanation is that the Senate language means that an emphasis on strategic research is actually equivalent to investigator-initiated, peer-reviewed, basic research in the national priority areas previously identified by the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET). Currently

these areas are high-performance computing, advanced materials, manufacturing research and education, biotechnology, and global change.

A White House Vacuum

Part of the problem is that the Clinton administration did not adequately address the early development of a policy for basic research within their broader science and technology agenda. As a result, a policy vacuum developed, drawing in Congress and other bodies.

As I will note later, to address this the White House has scheduled a policy conference in late January called "Science in the National Interest" to assist in developing the needed basic research policy. Both Homer Neal and I have been invited to attend.

What will be on the agenda? The importance of basic research in meeting national needs. And, how to embrace the significance of basic research while at the same time setting priorities for the returns expected on federal R&D spending. It's a delicate situation. We think that this is going to be a most significant meeting, and we hope it will open up the discussion once we have a better idea of the Administration's goals.

Some Work on Language

John Armstrong has done an excellent job in attempting to define the terms used in the ongoing debate. According to Armstrong, "basic" research is research that leads to new understanding of how nature works and of how its many facets are interconnected. He does not favor the term "curiosity-driven" since it conveys an air of frivolity to taxpayers and Congress, and since it is not as near the mark as "understanding-driven."

"Applied" research is research aimed at making something work. But now we can see why these definitions blur, since often a useful strategy to make something work is to understand some aspect of Nature's working. Conversely, many scientists who achieve new understanding

from their basic research are highly motivated to turn that understanding into some new device or process, some new, made thing.

From this vantage point it is easy to see that basic research is important to a country or a company and NOT a luxury. The importance of basic research stems first from the fact that from time to time it discovers or creates unexpectedly vast new possibilities for achieving society's goals.

"Strategic" research is research that can reasonably be expected to contribute to goals, including understanding-driven basic research. Strategic research is not synonymous with applied research. It is a categorization which is important primarily to the supporters, not the doers of research. It is research in scientific areas which are good bets to be helpful in reaching agreed-upon goals. It can be basic or applied; indeed, in the strategic areas, it is the task of those who support research to support the complete spectrum of research, from the most basic and fundamental to engineering and applied research.

There is no inherent conflict between strategic research and research done by individuals driven by a desire to understand nature. The strategic goal for which research is supported and the motivations of individual researchers are different things, and they are measured—if along different dimensions.

"Discipline-only-driven" research is what most of us think of as basic research in our own fields. In addition to "understanding-driven research," the other way in which major new insights are occasionally obtained is as an unexpected byproduct of applied research; e.g., Penzias and Wilson's discovery of the 3 K cosmic background radiation when trying to improve radio telecommunication technology.

Why is the scientific community afraid of strategic research? First, there is a concern that widespread use of the categories of strategic

research will lead to disproportionate funding of such work—to the detriment of what might be called "discipline-only-driven" research. Also, there is a concern that the misunderstanding of the complex interplay between basic and applied research will lead to the requirement that even the basic research be done according to agency driven timetables and milestones (even though this doesn't work).

What Are the Real Dangers?

Erosion of the American Research Enterprise

The American research enterprise is a triad comprised of research universities, national laboratories, and industrial R&D labs. The latter two are rapidly being forced to downsize fundamental research, while the first is under great stress.

In addition, the following trends are occurring:

- continuation of the downsizing of industrial R&D
- the downsizing of basic research in key federal mission agencies (e.g., space science in NASA, 6.1 research in the Department of Defense, basic research in the Department of Energy with the demise of the Superconducting Supercollider)
- the downsizing and loss of mission of the national labs
- the great stresses on the American research university (e.g., GUIRR study)

Our nation faces a great risk if it allows the current downsizing of basic research to continue.

Clearly it is possible to pick out areas of basic research which are a good bet to help in achieving society's goals. But it does not follow that we know what areas of science are NOT relevant.

Another reason why it is prudent to keep many of the discipline-only-driven fields healthy and vigorous is that they contribute strongly to the health of the whole of science, and in particular to the health of the so-called strategic areas, including basic research in the strategic areas.

Federal policy makers seem to be in hot haste to curtail exploratory basic research at universities. The short-term benefits of such a move are questionable. The longer-term consequences could be disastrous. Congress wants federally supported research to be highly focused on specific national goals. Unfortunately, at the same time exploratory basic research is also being curtailed at major companies and at national labs.

The Need for Change in the American University

I am certain that many of you have had a chance to take a look at the Fall 1993 issue of *Daedalus*, an issue devoted entirely to the American research university. In an article by Kenneth Prewitt of the Rockefeller Foundation titled, "America's Research Universities Under Public Scrutiny," Prewitt states that the general public has taken to asking research universities, "What have you done for us lately?" And, "Is the product worth the price?" Prewitt added, "Public skepticism toward institutional sectors has become a fact of American political life. No one would be foolish enough to suggest that universities are exempt from this public skepticism.

If the funds now supplied to NSF were diverted from the support of academic exploratory research, they would add comparatively little to a huge activity. As a result of the diversion, the universities would be injured, and our world leadership in understanding nature would be injured.

What Can We Do About It?

Where might we go from here with respect to protecting the basic research capability of our nation? How could we proceed to improve the situation? Clearly we must show the benefits of our work. Although there will be some of our colleagues who would prefer not to have to do so, we must make our case—learning to become better at politics, if you will for the support of basic research.

Making the Case for the Importance of Basic Research

Frank Press poses the following question: What do the following advances in technology have in common?

- modern agricultural products
- biotechnology
- designer drugs
- MRI systems
- penicillin and other antibiotics
- industrial catalysts
- CNC machine tools
- digital signal processing
- the modern computer
- frequency modulation
- masers and lasers
- ion implantation
- computer work stations
- plasma etching
- RISC computers
- artificial intelligence and neural networks
- compilers
- word processing
- image processing
- instrument landing systems, loran, inertial guidance
- nuclear energy

Press notes that this is an incomplete sample of technological breakthroughs based on fundamental science and engineering—and universities played an important role in their

conception, development, demonstration, and implementation. Many were serendipitous consequences of fundamental research in that the investigator did not anticipate the commercial application.

This sample list is the twentieth-century prologue to a twenty-first century paradigm in which new knowledge will be the currency of successful industry—an age of knowledge.

Each nation has to find its own route to economic success. For the U.S., and possibly for a few other advanced nations as well, it may be that their comparative advantage will be leadership in research and training in fundamental science and engineering.

We also have to put things in context. Industry invests over $55 billion in R&D (and generates $2G in sales). Industrial Research Institute notes, "Since industry allocates only a small fraction of its R&D effort to basic research, the success of our industrial R&D effort depends heavily on America's universities for new knowledge and highly trained scientists and engineers."

The Setting of Priorities

A recent National Academy panel has proposed a new framework for establishing priorities in science and technology.

We could work with one of two premises:

i) The U.S. should be among the world leaders in every one of the major fields of science. Then, if something does happen, you can rapidly jump in, e.g., superconductivity in Switzerland. This also gives a stable level of effort. (Note: This accepts the fact that some science may turn out to be important.)

ii) The U.S. should maintain clear leadership in some major areas of science. (Note: This accepts the fact that some science will almost certainly be important.)

One example is the SSC. Should the U.S. be alone at the top in fundamental particle physics, for example? Probably not. If not, do we need to have the SSC to be among the leaders or can we be part of an international consortium?

Is this likely to have any impact given the present political climate?

White House Leadership

In his first days in office, President Clinton said, "Scientific advances are the wellspring of the technical innovations whose benefits are seen in economic growth, improved health care, and many other areas." However, to assure the highest possible return on the public investment in science and engineering, there are new pressures for a stronger focus on research areas of known relevance and on greater accountability. A coherent national science and technology policy, a stronger industrial research mission, and a refocused mission for federal laboratories are essential components of this strategy.

A new cabinet-level National Science and Technology Council chaired by President Clinton was established in November of 1993. The NSTC has nine subcommittees, including a Fundamental Science and Engineering Research Committee co-chaired by Neal Lane and Harold Varmus and staffed by M.R.C. Greenwood.

What is its focus?

- How to allocate the $76 billion that the nation spends on R&D each year.
- To determine whether it should be spending more . . . or less.

As I mentioned earlier, the White House is sponsoring a forum in two weeks, which Homer Neal and I will be attending. One of the issues we must consider is the role of the NSF, which is to protect basic research. After all, only ten percent

of federal R&D is fundamental research. I believe that the key will be to position the NSF to play a critical role in working with other agencies with more applied missions. The NSF's main mission is to maintain scientific capability, not just to find new hot spots.

Other Ideas

In an article by Hans Bethe, he noted that we need to make better use of the national labs for the applied, strategic R&D necessary to respond to national goals such as competitiveness. And that we need to keep the universities (and the NSF) focused on the basic research necessary to provide the knowledge necessary to sustain these applied efforts.

We also need to get our own house in order. The Office of the Vice President for Research at Michigan is already planning to organize a follow-up conference after the White House forum to bring together representatives from the major research institutions and others from the scientific community to discuss exactly what such a group can and should do to make the case for supporting basic research.

What are some of the questions research universities must ask themselves now, in order to best continue our obligations to society? Jonathan Cole, Provost at Columbia University, has listed the following in his Fall 1993 *Daedalus* article on the dilemmas of choice facing research universities:

- What role should the research universities play in modifying or replacing the Vannevar Bush paradigm with a new framework that maintains American preeminence in science and preserves the research university's role as the principal incubator of scientific ideas and talent?
- How can research universities retain commitments from the federal government while simultaneously developing new sources of research support?

• Can and should university scientists redefine their scientific goals and reorient themselves toward new types of scientific and technological problems that have the potential for short-term practical results?

• Can research universities adapt successfully to changing research conditions by increasing the number of inter-university collaborations and consortia research efforts?

• Can research universities increasingly collaborate with international partners without undermining national economic interests and American support for their research?

• How can research universities develop new research relationships with the industrial and corporate world without entering into a Faustian bargain?

Concluding Remarks

I would like to close with the following statement by the National Science Board:

"As the twentieth century comes to an end, the U.S. is reaping the benefits of a half-century of extraordinary scientific and technological progress. The development of drugs and vaccines allows us to treat or prevent many once devastating diseases; agriculture has been made unimaginably productive; entire industries, such as semiconductor manufacturing, have arisen; work and leisure have been remade; and vast quantities of information now flow freely around the globe.

"Each of these transforming advances has its origin in a wide array of discoveries made by scientists, engineers, and mathematicians pursuing a deeper understanding of the world we live in. Using fundamental methods of scientific inquiry, these men and women have reshaped our world. This endeavor is basic research.

"A NSB Commission has noted that research can be undertaken both to achieve

strategic ends and to increase the base of knowledge. Basic research is the foundation and essence of both, assuring a deep reservoir of knowledge and providing choices and flexibility for addressing future needs. Moreover, in the age of knowledge, the problem solving approach of basic research helps prepare minds for work in all walks of life.

"Basic research is one of many forces that contribute to the nation's economic development. Its benefits will be achieved only in connection with other parts of the nation's scientific and technological enterprise, including applied research, education, technology transfer, and development, innovation, and manufacturing.

"Basic research is not intended—nor should it be expected—to advance short-term goals. Rather it is an investment that, like education, takes time to mature but has tremendous practical payoffs in the long run.

"Assuring the knowledge base appropriate for economic growth, long-term job creation, and social well-being requires a conscious commitment to strong and consistent long-term support for basic research and education. Providing requisite support for this process is a matter of strategic national importance."

Thank you very much, and I would be happy to answer any questions you may have.