The Role of the Academy in the Future of Science

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Good morning and welcome to you all. I am glad that so many of you were able to make it to Washington for this 132nd Annual Meeting of the National Academy of Sciences. I want to talk to you today about the role of the Academy in the future of science.

As we all know, governments today are questioning both their level of support for science and the rationale for this support. Our government is certainly no exception. Therefore, as scientists, we need to try harder than ever before to explain to the public why we do science and why it is so productive. And, as a community, there is an urgent need to do much more to bring the rich resources of science in the United States to bear on some of the most pressing problems of this nation and the world.

I see our Academy as the obvious place to lead these efforts. And I would like to use my time with you today to outline what we are doing, so as to encourage your participation and ideas.

Let me start by emphasizing that the research we all do clearly brings great benefit to our society. Economists who have carried out serious studies of the productivity of fundamental research have concluded that scientific, medical, and engineering research are enormously beneficial as a social good, with rich benefits to the economy and to society as a whole. In fact, different analyses find that the fundamental scientific research carried out in the United States produces a rate of return on the financial investment of between 20 and 50 percent per year — an enormous yield compared to other organized endeavors.

This rate of return from our research investments applies both to research carried out in universities and to research carried out in industry. But the contribution made by research in universities is even further enhanced by the simultaneous production of human capital. By this I mean the large number of energetic and talented students and postdoctoral fellows who leave the universities with meaningful research experiences, and go on to make important contributions to the scientific and technical communities in our country.

If we are so productive, why do we in the scientific community need to become energized on this issue? The reason is clear. Unfortunately, our research investments are undervalued today by American citizens. There seems to be an impatience in America that does not serve us well. We have a short attention span, and, because of that, we are not a country that believes strongly in the value of investments.

We have recently seen a retrenchment of the investment in fundamental research by many of our major corporations. In part this is attributable to rational decisions that reflect major differences between what economists call the "private," versus the "social," rate of investment return. This difference arises because the fundamental research carried out by industry is inherently many years away from potential products. Therefore, a major portion of that research is likely to benefit companies other than the one that actually paid for the research. The return on this type of investment for our society as a whole — the social rate of return — has thus been estimated to be about twice the private rate of return to the company that actually makes the investment.

The retrenchment in industrial investment in basic research has another cause: American impatience. Norman Augustine, the distinguished Chair of the National Academy of Engineering and CEO of Martin Marietta, tells a disturbing tale based on his own experience. Several years ago, his company called a large public meeting in New York to announce a major new research initiative that he was extremely excited about. To his surprise, the investment community was disappointed: They had been hoping for an announcement of a major takeover but instead were told of the company's long-term research plans. The price of Martin Marietta stock immediately dropped by more than 10 percent, and it continued to slide for two more years. Their analysis subsequently showed that, on average, stockholders hold their stock for only 18 months. In this sad tale lies an alarming message and a wake up call for America.

In an environment that discourages fundamental research by industry, the government's role has become essential. The investment that we make as a nation in fundamental research through government-supported projects is crucial to keep America a first-rate world power and maintain the vitality of our civilization. Yet today, the same shortsightedness that motivates the American stockholder threatens to take a similar toll on all of our national investments.

In this time of severe budget pressures, our nation needs to recognize quite clearly that all expenditures are not the same. For a family, the funds spent on educating children brings far greater benefit than the same amount of money invested in new electronic equipment designed to entertain. For a nation, the money invested in both education and in fundamental research forms the legacy that we must leave for our young people if we are to provide for their future. In Washington today, there is an absurd focus on the idea that our young people will prosper in the 21st century if we simply balance the budget for them. As scientists, we know this to be unwise and untrue. Our voices need to be much more effectively heard throughout the nation concerning the need for investment in education and research.

But how can we best explain to the American public why fundamental scientific research turns out to be such a wise, long-term investment for our country's future? The Academy has been struggling with this important question for a long time. In the summer of 1993, we issued an important report entitled *Science, Technology, and the Federal Government: National Goals for a New Era.* In this report, we argued persuasively that the United States must remain among the few world leaders in each and every major field of scientific research, while being the clear leader in particularly important fields.

More recently, we have initiated an Academy project led by Jack Halpern, your Vice President, which is attempting to improve the communication of scientists with the public through the development of a set of powerful case studies — each overseen by an Academy member. These case studies take a recent development that everyone cares about — such as genetic testing and diagnosis — and traces its origins, explaining how the benefit today has depended on previous fundamental scientific investigations of an unpredictable and untargeted nature.

Now that some of the case studies are in hand, the larger problem remains: how to package this information in a form that is accessible and understandable to the average American — for example, through videos, pamphlets, or museum exhibits. I am counting on Jack to solve this problem, and I am sure that he would very much appreciate your ideas.

As members of the Academy, we must be much more aggressive in addressing the fundamental issue of communicating what we do and why we do it. Only if we are successful in this endeavor can we expect our national investment in scientific research to be preserved and expanded.

I believe that an important component of any strategy involves providing a much more effective and meaningful science education for all of our citizens. This education must start in kindergarten and continue through every year in school. It must excite young children about science and give them the freedom to explore and solve problems. And it is well past time to recognize that no one should graduate from college in the 21st century without a substantial understanding of the science and technology that dominate their lives.

As you all know, the Academy has played a major role in developing National Science Education Standards for the precollege years. Nearly 40,000 copies of these Standards have been distributed in draft form, with reviews received from thousands of individuals and 140 focus groups from every state in the nation. The final version is now in production under the guidance of Richard Klausner, the Academy member who has led this effort with great skill and dedication. In preparing this document, he was able to harness the focused efforts of more than 40 of your colleagues, whose contributions were absolutely essential to providing the scientific rigor that the Standards now contain. The names of some of these Academy members are shown on the first slide.

Don Kennedy has already spoken to you about the enormously successful Convocation on College Science, Mathematics, Engineering and Technology Education that he led at the Academy two weeks ago. This Convocation begins a year of national dialogue, punctuated by four regional meetings that will move the effort from analysis to action.

There is a tremendous amount yet to be done. In her stirring keynote address to the Convocation, Donna Shalala, the Secretary of Health and Human Services, reminded us that it will not be enough for our science faculties to teach more science classes to more students. We must also reach out to our colleagues in other departments to help them include relevant science topics in their teachings.

Two painful experiences of the past few years come immediately to mind. When the National History Education Standards were released last fall, we were astounded to find that science was hardly mentioned at all in the document. Even worse, during our own preparation of the National Science Education Standards, we encountered an alliance of educators who insist that there is no such thing as objective reality. According to a so-called post-modernist view of science, had science developed differently over time, we would be faced today with a different set of scientific truths. Thus, for example, the fantastic tale of scientific progress in this century that has led to our present detailed understanding of how human muscles work — extending all the way to the atomic level — is presumably viewed as only one of the many answers we might have arrived at had science progressed in a different way.

This is absurd. Do most Americans leave college as confused about science as some of their professors? If so, we can hardly expect them to value and appreciate what we do.

Both the precollege and the college efforts presently emanating from the Academy are extremely ambitious ones: They envision nearly an order of magnitude change in both the nature and the quantity of the science education that we provide to most Americans. I view these projects as an integral part of our mission to create the public support and understanding necessary to assure that our nation's investment in science is maintained, now that the Cold War no longer provides the motivation for such investments.

Creating a much greater appreciation for science in this country is a very serious responsibility for our community. I welcome suggestions from all of you.

With your indulgence, I would like to briefly present my own way of explaining why science is so powerful and productive, based on my experience as a cell and molecular biologist. My basic conclusion is that unexpectedly powerful "system properties" emerge from what might be called organized complexity. This is very obvious when one considers what happened during biological evolution. But I claim that exactly the same type of powerful system properties are emerging from science and technology as we generate and exploit highly organized collections of knowledge.

To give you an idea of what I mean by "powerful system properties," consider the fundamental unit of life, the cell. This simplest living thing is a highly organized chemical system, consisting of a collection of catalysts that work together to reproduce the entire collection of catalysts. It is quite amazing that such a thing could ever exist. Some of you will remember the surprising prediction, described in Freeman Dyson's fine book "Disturbing the Universe," that our civilization will eventually design a robot that will be able to go out into space, use materials in space to build more robots of the same type, move on, and thereby populate the distant universe. The biological engineering that produced the living cell is directly analogous. We generally fail to appreciate the cell, because we take it for granted. Yet the cell is a chemical system whose components catalyze the production of more of itself, directly analogous to Dyson's robot.

Today, the simplest known cells are tiny bacteria containing about 500 different catalysts in the form of 500 different proteins that act to replicate the whole system of catalysts. What do 500 chemical reactions that are connected to each other actually look like? The next slide displays an actual example taken from biology. Reactions of this order of complexity, organized in the appropriate ways, have created the analog of Freeman Dyson's robot, the self-reproducing cell and its many descendants that have populated the earth for more than 3 billion years, transforming the earth itself and its atmosphere. I find this astounding and amazing.

Perhaps the most striking way of illustrating my central point is to talk about our own brains. Somehow, a network of nerve cells with billions of connections produces "human consciousness." Human consciousness is qualitatively different from the chemistry that lies behind it. It is a property that comes out of — but seems beyond and much more than — the many cellular connections from which it is formed.

I think that something very profound and non-intuitive lies behind the facts that I just mentioned. When one takes a lot of complex entities, molecules — and connects them in highly organized, specific ways — very powerful system properties can emerge that one would never have predicted from the components themselves. In other words, the system becomes enormously more than the sum of all its parts.

In science and technology, scientists and engineers use their intelligence to combine physical entities on the earth in unusual ways. And as the results build upon each other, we often greatly surprise ourselves: Emergent properties appear that are much more powerful than any of the individual components. Consider, for example, the whole computer and telecommunications revolution; nobody could have imagined how all the pieces of knowledge about electronics, materials, and mathematics would fit together and keep on developing in ever more powerful ways. In the end, what has been produced is something that is much different and more wonderful than anything anybody expected.

Do you remember the U.S. patent commissioner in the 1860s who suggested that we might abolish the Patent Office because everything that was worthwhile had already been discovered? Anyone who looks back at the predictions made 30 years ago or even 10 years ago will recognize how wrong those predictions were — instead, the past proves that emergent properties come out of science and technology in unpredictable ways. All we can say is that, as scientists increase the amount of knowledge, the ways of interconnecting those bits of knowledge increase combinatorially, so that the emerging systems we develop are going to be increasingly impressive and amazing. And we must fully expect such a future.

As science grows in importance, so do the responsibilities and roles of our Academy. The whole world looks to the scientific and technical community in the United States for enlightened leadership. In these days full of doomsayers about the United States, the communities that we represent stand out as a rich resource for the future strength of our nation.

One of our important jobs at the Academy is to make our nation's leaders aware of the tremendous resource we represent — we being the millions of Americans who use scientific and technical expertise in our professions. Through our partnerships with the National Academy of Engineering and the Institute of Medicine in the National Research Council, we are perfectly poised to exert both national and world leadership on a huge number of issues of critical importance. But to be effective, we must choose our targets carefully, enlist the right people in our efforts, and thereby provide dramatic "existence proofs" of the greatly enlarged role that our communities can play in both national and world affairs.

At the national level, our influence as scientists is greatly enhanced by the work that we do through the National Research Council — our major device for bringing the nation's science and technology expertise to bear on national policy issues. I will present a brief status report on the NRC at tomorrow's business session. To summarize what I will say then, I believe that we have made substantial progress toward two important goals: 1) focusing our resources on important issues, and 2) making sure that every event we sponsor and every report we publish is a contribution of which each of us can be proud.

I want to spend the remainder of my time focusing on another important issue: bringing the energy and expertise of the world's scientists to bear on major international issues.

The more we recognize the power of science and technology and what it can do for society in practical ways, the more we recognize that the world in the future is going to be a very different place. There will be countries like ours which presumably will be engaging in a full spectrum of scientific activity and enjoying the benefits. But there may be other countries without any significant scientific capacity at all. And the gap between these two types of societies could grow wider and wider. The old view is that science is a luxury for a developing country and not an important priority. Such a view is completely wrong and a precursor to disaster.

Science is fundamental to driving economic development in more sustainable ways and to improving the life of people everywhere. And this is going to become even more true in the next century, as the power of science and technology in the developed world expands and makes possible more and more amazing things.

The World Bank came to the Academy recently and asked us if we could help them think about the role of science and technology in international development. This has led us to consider what the minimum conditions should be in a developing country for science to become truly useful and to enable scientists in that country to contribute to wise decision making. First of all, it is clear that science and technology expertise must be local. In every country, there must be a core of educated people who can serve as local adaptors of the expanding world science and technology knowledge base. It is an important challenge for the Academy to try to define what exactly the science and technology expertise should be, at a minimum, for different types of countries.

Following the lead of one of our members, Vernon Ruttan, we can divide the science and technology expertise required into three main areas: agriculture, environment, and health. The next slide shows that there are at least four different types of *local* connections required to enable the science in each of the three areas to serve a developing country. First, the regional science and technology expertise has to be tied to some funding source: It can't exist without support and infrastructure. Second, it has to be tied to the students in universities that bring vitality to the enterprise and build capacity for the future. Third, the expertise needs to be connected to an action arm — designated here as "direct service providers" — such as agricultural extension workers or health care providers. Last but not least, the science and technology resource has to be tied somehow to the people who make policy in the country. It has to be connected to government decision making, so that the wisdom of that resource can be used.

The United States turns out to be very unusual in that we have devices that are intentionally designed to connect the science and technology expertise in our nation to government policy. One of the most important of those devices is, of course, the National Research Council. The NRC makes use of thousands of volunteers who study specific problems that require science and technology expertise, and we do this in a strictly independent way for our government.

If you go around the world, you will find that the NRC is absolutely unique. There is no other country that has our kind of organization for supplying independent science and technology advice to their government. Even Great Britain lacks such a mechanism. At the Population Summit of 60 of the world's science academies held in New Delhi, India in the fall of 1993, many of the academies asked if we could help them establish the same NRC-type of linkage with their own governments.

We have had a model program with Mexico of which we should all be proud. About four years ago, my predecessor, Frank Press, and his executive officer, Phil Smith, helped to set up a process to enable the Mexican Academies of Science and Engineering to provide advice to their own government. Governments do not necessarily want independent advice. And so, the plan they developed was to set up several joint studies with the Mexican Academies where half of the members of the committees were from the U.S. and half were from Mexico. By studying important Mexican problems using NRC procedures, we hoped to demonstrate to their government that this kind of advice can be useful.

The problem that they chose to address in the first study was the Mexico City water supply. The Mexican scientists got their government to agree to the idea that this Academy study would be done independently, carried out by the procedures of the National Research Council, including our anonymous review process.

This report was released last month in Mexico with considerable fanfare and publicity. As shown on the next two slides, the report is printed in English in one direction — and when you turn it over on the back, in Spanish. The study was so successful that the Mexican government has now helped to start a National Research Council in Mexico. In fact, a photo of our foreign secretary, Sherry Rowland, at the inaugural ceremony last month is shown on the next slide.

I view the experience with Mexico as a tremendous success, and as a prototype for the kind of connection between local science and technology expertise and government that we can help other Academies make throughout the world.

This prototype has recently become a major focus for our international activities at the Academy. New study projects with the Academies in India, China, and the Middle East are aimed at accomplishing the same objective. In all these regions the leading scientists are frustrated by the fact that they are not sufficiently connected to policy decisions, and they seek our help in correcting this situation.

I want to focus for a few minutes on the problem of how we can most effectively connect the world's best expertise to the scientists and engineers in developing countries. We have in developed countries a rapidly advancing science and technology knowledge base that is exploding and becoming increasingly useful for addressing world problems. We do not want that information to just sit there — we need to connect it to the groups of scientists and engineers who serve as knowledge receptors and adaptors in each developing country.

Our new electronic communication devices make possible a qualitative change in past practices, and we need to think about how we can use these technologies to create a new type of international science. I believe that we should be thinking about developing a prototype for a set of carefully designed data and discussion platforms on the Internet. Each platform should be specifically designed to connect us to the scientists and engineers in developing countries in a particular field, such as agriculture, water science, or health science. These platforms would have to be divided into sensible subcompartments that are easy to use, so that even a novice could make use of them. For example, there could be one subcompartment on water purification, another on arid land irrigation, and so on. Included in each platform would be a database that would provide access to the most useful recent review articles — as well as to abstracts of the literature already compiled in other electronic databases. But another crucial feature of such a platform must be its ability to facilitate appropriate e-mail connections on the Internet. Clearly, the ability of scientists throughout the world to communicate with one another is key. What is really needed is a database that enables scientists in the developing world to connect electronically with other scientists who have the knowledge and experience that they need, virtually anywhere in the world.

Today, we still lack global Internet access. But we are going to have it soon: Satellites and other devices are going to make it possible for a scientist to connect to Internet no matter where he or she is. This is an exciting tool that promises to alter the meaning of the term "international science" — providing that we make wise decisions now, as we plan for the future.

Let me conclude by using the area of agriculture, where we have had the most experience with international science, to illustrate some of the important questions that can only be answered by scientists. These questions are of three kinds.

1) First, as the next slide shows, we need to address the issue of building local capacity.
Considering a developing country of very modest means:
What is the minimum number of local scientists required to enable the country to utilize world scientific resources to meet local needs?
a) Exactly which types of expertise are required?
b) How should these people be organized and supported?
c) How can quality be maintained?
d) Is it essential to maintain a core of fundamental research in plant science, for instance, in addition to research of a more applied nature? If so, why?

2) There are also important questions that concern connectivity — about how scientists in the U.S. can be effective in facilitating the development of science capacity throughout the developing world:

a) Can we create special programs for foreign students in U.S. universities to better meet developing country needs?
b) Can we create a vigorous new type of international science through the skillful use of electronic communication tools?
c) How can we establish valid merit review panels to help developing countries optimize their use of limited resources?

3) Last but not least, I present an important question that concerns our political will as a nation to exert world leadership on these crucial issues:

What can we do to help convince the American public that using our resources to help build a strong science capacity in the developing world is in our own national interest?

In ending, let me emphasize that I have raised these questions today because I want to encourage your participation in all of our efforts in the strongest possible way. I urge you to write, phone, e-mail, or otherwise communicate your ideas. This is your Academy, and we need your help in bringing science and technology to their proper place of prominence in both national and world affairs.