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TRANSCRIPT

"What We Don't Know: Challenges for the Next Generation"

By

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Charles M. Vest is the fifteenth President of the Massachusetts Institute of Technology and Professor of Mechanical Engineering.

Dr. Vest has set three strategies for maintaining and enhancing the excellence of MIT: identifying the most critical emerging directions in education and research, providing a strong financial base for MIT's programs, and improving the value and efficiency of services in support of these programs. In recognition of the increasing interdependence of economic, technological, environmental, and political systems, both in the United States and throughout the world, his priorities include building a stronger international dimension into education and research programs, developing stronger relations with industry, enhancing racial and cultural diversity within MIT, and rebuilding public understanding and support of higher education and research.

In this latter capacity, Dr. Vest serves as a member of the President's Committee of Advisors on Science and Technology, the Massachusetts Governor's Task Force on Economic Growth and Technology, the National

Research Council Board on Engineering Education, and is vice chair of the Council on Competitiveness. He is president of the National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc. (GEM), and a director of IBM and the E.I. du Pont de Nemours & Company. In addition, he was also chairman of the President's Advisory Committee on the Redesign of the Space Station.

Dr. Vest earned his B.S.E. degree in mechanical engineering in 1963 from West Virginia University, and both his M.S.E. and Ph.D. degrees from the University of Michigan in 1964 and 1967, respectively. As a member of the faculty at MIT, his research interests are in the thermal sciences and in the engineering applications of laser and coherent optics.

Good afternoon. It is a pleasure and an honor to be with you.

Today I would like to talk about what we don't know...and why discovery and innovation is so important to our future, as individuals and as a society.

Let me begin with an allegorical tale:

A woman died and found herself standing before St. Peter at the Pearly Gates. When she asked if she could enter, St. Peter said, "First, you must pass a test. I will give you a word. If you can spell it, you can enter Heaven. The word is love."

"L.O.V.E," she said, and she was warmly welcomed into Paradise. Then St. Peter said, "I must run an errand. Could you watch the Gates for a couple of hours? If anyone comes, just give them the test."

An hour later she was astounded to see her husband standing there. In his shock over her demise, he had lost control of his car and crashed into a tree. "Honey, is that you?" he said. "Is this Heaven? Can I come in?"

"I hope so Dear, but St. Peter has left me in charge and I must administer a test. I will give you a word, and if you can spell it, you can enter Heaven and spend Eternity with me."

"What is the word?" "Czechoslovakia."

Now those of us, and especially you who are studying or just beginning your careers, are in a similar position. We look through the gates to the future and see a potential golden age for engineering and science - because we have so much to discover, so many ways in which to serve humankind, and so much to contribute to many of society's most difficult problems.

Yet suddenly we are confronted with skepticism about the value of what we do, and with even serious people like John Horgan writing about The End of Science. Cassandras talk about poor job markets, and our nation's government and industries are reducing their financial commitment to research.

In a sense, we are being given a test to determine whether we will be able to enter a new golden age of science and engineering. The test is being administered through cultural attitudes, through public policy, and through changes in our industries. We must pass the test, and it won't be easy. Doing so will require that we ourselves change in some dimensions. It will be a lot harder than learning to spell Czechoslovakia.

The test will require that we do three things:

- First, engineers and scientists must become much better at explaining what we do, why we do it, how we do it, and how it benefits humankind. We must be clear about how it benefits our public patrons and private-sector partners. Above all, we must emphasize what we do not know, and why these questions are important, rather than just brag about what we do know.
- Second, we must abolish the debilitating and false distinctions between basic research and applied research. It is an anachronism, but it confuses serious and concerned policy makers no end.
- Third, we must learn how to conduct truly interdisciplinary studies, research, and work. We must maximize synergy and learn to be adaptable and agile in solving problems. We must do a better job of integrating the continuum between discovery, engineering, policy, and business.

THE CURRENT CLIMATE

I would like to begin with some observations on recent history and the current climate for innovation and scientific inquiry.

During the last decade, many of our nation's industries became competitive again in the rapidly changing world economy. To do so, we had to discover how to manufacture better - how to produce things more cost effectively, with vastly higher quality, and with much faster product cycle times. Now, I believe, we will face a new set of challenges that will require improved mechanisms for the discovery of new knowledge, and faster innovation in response to it.

These are challenges that are not always easy to recognize or meet - as John W. Gardner pointed out in the early 1960s, in his book entitled Self-Renewal. He described the paradox that innovation and scientific inquiry require at least a modest level of affluence, yet the comfort of affluence often undermines a commitment to innovate, and observed that "If affluent individuals (or an affluent society) commit themselves unreservedly to the conservation of their resources, affluence can be a deadening force." On the other hand, he noted, "Individuals and societies living close to the margin of survival often cannot afford to take the chances required by innovative action."

For those committed to science, engineering, and technological advancement, it's a classic and troubling Catch-22. A rich and complacent society sees no pressing need to alter the status quo, while a lean and desperate society hasn't the resources to invest in innovative exploration.

Viewed from the narrow perspective of economic productivity, the situation is almost ludicrous. For example, many economists accept the assertion that at least half of America's post-1945 economic growth is due directly to scientific and technological innovation. Yet the richer our society becomes, the less willing it seems to fuel its engines of prosperity. National Science Foundation figures for the period from 1990 to 1995 show an overall decline in constant-dollar R&D spending by both government and the private sector. As a percent of Gross Domestic Product (GDP), overall R&D spending hovered between two-and-a-half and three percent between 1983 and 1993. Since then, it has slipped below the two-and-a-half percent mark.

Nowhere is this troubling stagnation more apparent than in the proportion of the U.S. federal budget that is devoted to research and development. I recently co-authored an essay with last year's Woodruff Lecturer, Lockheed Martin CEO, Norman R. Augustine, in which we suggested that American society is, in effect, consuming its economic seed corn by reducing its commitment to research and innovation. We pointed out that payments to individuals (Social Security, Medicare, etc.) are combining with interest on the national debt to crowd out all other forms of federal spending, including spending on research and technological development.

In 1963, the year John Gardner issued his warning about the deadening effects of affluence, payments to individuals and interest on the debt accounted for 35 percent of federal spending. Defense spending accounted for 48 percent of federal expenditures. Everything else - including NASA, the National Science Foundation, the Federal Aviation Administration, the Federal Highway Administration, and a host of other agencies that sponsor research, development, and education - accounted for just seventeen percent of the federal budget.

That was a modest enough investment, given the enormous societal return. Yet today, the share of the federal budget devoted to interest payments on the national debt and payments to individuals has risen from 35 percent to 74 percent, while the "all other" category, which includes investment in research, education, and innovation, has sunk to eleven percent. By the end of this decade, it is projected to fall yet again to just nine percent of all federal spending.

Clearly, the phenomenal value and importance of knowledge generation and innovation is somehow getting lost in our discussion about how to allocate our public and private resources.

Furthermore, some of the best measurements of value in scientific and technological progress are often ignored in favor of diatribes against the lack of achievement in certain specific areas. The time-honored formula for this is that "we can put a man on the moon, but we just can't seem to ...." You can finish the sentence any way you like. Create a vaccine against HIV? Cure the common cold? Eliminate traffic jams?

And yet, some of the most remarkable achievements of science, technology, and engineering seem to pass almost without notice. In 1900, for instance, life expectancy at birth for the middle and upper classes worldwide averaged around fifty-five years. Today, in all but the world's very poorest societies, global life expectancy has risen to seventy years - a gain of two months per year throughout the century. According to a 1995 report conducted under the auspices of the National Academies and the Institute of Medicine, "Sanitation, nutrition, transportation, communication and other technologies have combined with biomedical research and medical technologies to produce this profound demographic shift."

Today, scientists and engineers from many fields are contributing to major new advances that will further accelerate this trend. The mapping and sequencing of the human genome have been made feasible by advanced combinatorial mathematics, computer science, and robotics. Advances in chemical engineering have helped scale up biotechnical processes to produce usable quantities of new medicines at controlled costs. Advances in computer science and engineering have provided the ability to model and visualize complex molecular processes, and to analyze the huge amounts of data required by genetic studies. Condensed matter physics makes possible the microscopic probes needed by doctors and biomedical scientists. Materials research is a critical component of the effort to develop precision delivery mechanisms for molecular drugs.

Synergy is an overused word, but it has genuine significance in the world of science, engineering and technology. The problems we must address are increasingly complex and multifaceted.

We must commit ourselves to broad-based, wide-ranging scientific and engineering inquiry, with confidence that the cross-pollination among fields will greatly strengthen the value and impact of science and technology.

IN PURSUIT OF THE UNKNOWN

My principal purpose in this lecture is to suggest a few areas of ignorance. By thinking about what we don't know, we can identify avenues of scientific and technological inquiry that have potentially high impact. There are profound questions to be pursued in such areas as medicine and biology, the brain and neurosciences, organizations and systems, information technology, energy and the environment, and the physical universe - to name but a few.

I hope this will be a modest demonstration that we are nowhere near the end of science. We have a very great deal left to learn, and a vast amount of room in which to use that knowledge to make improvements in our lives, in our societies, and in the quality and vitality of our biosphere.

MEDICINE AND BIOLOGY

Consider medicine and biotechnology. Our evolving understanding of basic cellular processes in all living organisms is improving our ability to understand and, ultimately, to prevent or treat cancer - but we need to know much more.

We now know that genes are a key to the operation of cancer, but we do not know all the specific genes whose mutations contribute to its development and progression, nor do we understand the mechanisms by which they act. Identification of such genes may lead to diagnostic tests that can identify high-risk individuals or identify which cancers are treatable by radiation or chemotherapy.

We also do not know how and why cells die. The suppression of normal, programmed cell death - a process called apoptosis - is believed to be involved in the growth of certain cancers. Promoting the controlled death of particular cells is the objective of much of cancer treatment. Interestingly, many chemical therapies for cancer were discovered empirically. Only recently has the role of genetics and programmed cell death in their operation begun to be understood. This also has implications in the understanding of auto-immune and neurodegenerative diseases.

Further advances in health-related fields will come from the increasing interaction of biology with other scientific and engineering disciplines, including mathematics. For example, we do not know how viruses form their elegant, geometric structures from commonly occurring protein building blocks, nor do we understand the role of these structures in the infection process. By applying mathematical methods to analyze viral protein structure, we hope to gain sufficient understanding of the infection process to aid in the development of antiviral drugs for applications from HIV to influenza.

And finally: We do not know how living cells interact with molecules of nonliving materials. The answers to this question hold the promise of making great strides in the development of artificial limbs, organs, and tissues. The opportunities here have spurred cell biologists and researchers in such areas as materials and chemical engineering to work together in the emerging new field of biomaterials.

THE BRAIN AND NEUROSCIENCES

In all of these areas, there are enough mysteries and potential advances to fire the imagination of an entire generation of scientists and engineers. But microbiology has many frontiers. Think of the brain. There is no greater mystery than how we learn, remember, think, and communicate, and there is no field in which major advances will have more profound effects on human progress and health.

There is every reason to believe, however, that continued, determined investigations of the biological basis of learning and memory, coupled with computer modeling, will greatly expand our understanding of the mind in the decades ahead. Not only is this an exciting scientific frontier, but a better understanding of the brain, brain chemistry, and the role of genetics may prove the key to vastly improved diagnostic and therapeutic techniques for chemically and genetically based mental illnesses such as schizophrenia and bipolar syndromes. Such advances would enable us to reduce both human suffering and the staggering costs of health care.

Specialists in the study of linguistics are seeking answers to another set of questions which can illuminate our understanding of the brain's physical structure and processes. Can we have thoughts that cannot be expressed in words? Can everything that can be expressed in one language be expressed in any other language as well? Cultural matters aside, linguists believe that the answer to both questions is no, but we do not know for sure. The answers are important if we are to understand the brain - or if we hope to perfect translation of languages by computer.

ORGANIZATIONS AND SYSTEMS

Like individual humans, societal systems communicate, adjust themselves to changing conditions, and intentionally change themselves. Understanding and predicting the actions of organizations is every bit as complex and challenging as understanding the processes of the individual mind or body. Still, we are beginning to establish some of the basic principles of human systems and organizations, even though we recognize that they remain much less deterministic in nature than the principles and processes of the physical world.

For example, we have a number of very reliable indices of national economic growth and many years of data on individual countries. Yet we do not know why national economies grow at such different rates either at a particular moment, or over time.

We know the likely factors that affect economic growth - education, capital accumulation, national investment in research and development, tax structures, trade policies, regulation, and basic legal and political structure. The relative importance of these factors and their interactions, however, are not known with any degree of precision, yet governments continue to develop and implement economic policy. In fact, governments routinely fall because they failed to live up to public expectations for growth - a situation where lack of knowledge of what works can contribute to worldwide political instability.

INFORMATION TECHNOLOGY

Some of the most profound and permeating changes in the nature of organizations and economies are being created by the rapidly expanding access to information. Even our largest and most dominant organizations for centuries - nations - will not be immune. We do not know what the consequences will be for the nation-state of the explosion in networked electronic communications.

The enormous collective bandwidth of the Internet makes it quite unlike the telephone, and it has the potential to create a new kind of "society," an entity in itself. We cannot predict if we will have a society of very local nets, centered around individuals and small groups, or a massive global society. We do not know the consequences in either case, nor how to steer these developments even if we could determine what outcome is desirable. But clearly, the outcomes will affect the very fabric of our communities and our own daily lives. Already we are faced with the development of extra-governmental systems that are not only rich in information but that operate around the world. One need only think of the problem of organizing and operating very large-scale, integrated, international systems such as a global air-traffic control system to see the magnitude of the challenge.

And on the interface of learning and information technology, we confront the fact that we really do not know how best to use our information infrastructure and new media to promote learning among children, particularly among those children whose home and community environments do not nurture and reinforce the most positive learning activities. Nor have we made more than a dent in the potential of information technology to promote lifetime learning among adults.

One feature of information technology - the vast archives of information available worldwide and the rapidly proliferating tools for accessing and manipulating this information - presents us with a particularly powerful and complex set of challenges. We do not know how the vast store of instantly available information can or will be understood and used.

Access alone does not assure that information can be located or understood. How can knowledge be gathered from disparate sources and then represented and shaped to enhance our understanding and our ability to use it productively? Can we strengthen our ability to transmit and understand concepts as well as simple facts? Can we better the odds that individuals of different ages, languages, experience, and cultures will be able to assimilate and utilize the knowledge to which they now will have shared access?

These are not new problems, nor are they ones that are defined only in terms of modern information technology, but they are increasingly compelling. We need to explore the power of the human mind to better locate and use to advantage what already is known, and to take in newly available information and grasp its significance. The grand challenge of bridging from information to knowledge to wisdom has no single technological solution.

ENERGY AND THE ENVIRONMENT

Even as we wrestle with the issue of how best to use our expanding information resources, we must also confront the fact that we still have a great deal to learn about how to use and sustain our natural resources. Once again, the connections should be readily apparent, since efforts to manage energy resources require better understanding of human organizations, economics, and information management.

For example, although economists can show that pollution imposes real social costs, markets do a poor job of encouraging individual and organizational players to incorporate these costs into their decision-making. Governments have to step in, but the approaches they have adopted to date have not, by and large, encouraged industry to be efficient and technologically innovative in solving pollution problems. We know how to design policy tools to control pollution efficiently, at least in theory. However, policy makers have not, until recently, relied on these policy instruments.

And on the supply side, renewable, safe alternative sources of energy are critical to our ability to enhance our quality of life while sustaining the quality of our environment. And yet, we do not know how to convert solar energy into practical, cost-efficient fuels for a variety of applications, nor do we know how to create advanced fuels for nuclear fission reactors.

On an even more fundamental level, we do not know how to extract all the useful energy from existing fuel sources. We know that a certain amount of energy is stored in chemical bonds, but when we burn the fuel to break those bonds, we waste much of the energy emitted as untapped heat and chemical by-products. And as anyone who has worked on technologies from spacecraft to pacemakers can tell us, the ability to milk every unit of energy from a power source could be a breakthrough of great practical importance.

Similarly, superconductivity, the ability of a material to carry electric current without loss of energy, is a phenomenon that could have broad practical applications.

THE PHYSICAL UNIVERSE

Each of the challenges I have outlined so far offers an extensive and worthy set of opportunities for the next generation of scientists and engineers. There are many other fields, including global climate systems and seismology, which offer equally compelling opportunities to improve the lives of millions of people. Yet I have not even touched on some of the biggest and potentially most dazzling challenges which confront us. After all, we still do not know how old the universe is, what it is made of, or what its fate will be.

Most basic knowledge of the physical universe is sought through both land-based and space-based instruments. The development of such instruments is made possible by the advancing state of the art in engineering, electronics, computers, and communications technology. In turn, development of instrumentation often advances our engineering capabilities.

Even though space-based instruments are doing much to advance our knowledge of the universe, we are still drawn by the adventure of human exploration of space. Our imaginations have been captured by recent indications of possible life on Mars, and the prospect of a mission to that planet presents exciting opportunities for space science and challenges for space technology. The biggest unknown at present, however, remains the crew itself. We do not know how to plan such a mission that would not result in a dangerously unhealthy crew. We must find ways to either dramatically shorten the journey or to develop some means of providing a more earth-like inertial environment for the long trip to and from Mars.

Taken together, these unanswered questions - about our physical universe, our social systems, our biological systems - offer a worthy and rewarding challenge to current and future generations of scientists and innovators. The answers to these questions are sufficiently compelling and relevant that they can be ignored or discounted only at great peril to our well-being and survival. That they will only be answered gradually and in fits and starts, in no way lessens their importance.

CREATING A CLIMATE FOR EXPLORATION AND INNOVATION

How do we create a climate that recognizes these challenges and supports their pursuit? How do we sustain the spirit of exploration and innovation?

Since the end of the Second World War, the United States has benefited immeasurably from what I like to call the innovation system. This extraordinary system consists of industrial, academic, and governmental institutions working together in a loosely-coupled manner to create new knowledge, new technologies, and people with the skills to move them effectively into the marketplace.

The system depends on the participation of several major partners:

- The federal government provides a large-scale commitment to a wide range of R&D activities.
- Private industry maintains its own R&D and training establishments, provides some funding for academic work, but most importantly, it creates products, jobs, and wealth based on new knowledge and technologies.
- Research universities (both public and private) not only conduct much of the federally and privately funded research but also train the scientists, engineers and other professionals who develop and deploy new products and technologies.
- Finally, state and local governments use their own dollars and federal grants to create and maintain public education systems and local infrastructure. Each of these partners is crucial to the success of the overall enterprise.

Our first challenge - and the foundation upon which all other achievements must rest - is to maintain a strong and expanding investment in the health of our innovation system. A substantial portion of this investment must go to primary and secondary education, so that more American students are exposed to the full value, utility, and beauty of science and technology as a discipline and as a career.

Beyond that, there are at least three ways in which the scientific and engineering communities can help themselves to meet the challenges I have posed for future generations.

The first of these is to accept and appreciate the value of making science and technology better understood by the public. The death last year of Carl Sagan is a sad reminder that we have far too few scientists and engineers who devote themselves to capturing the public imagination and creating a more fertile climate for scientific and technological inquiry. It was said of Sagan at his memorial service that "he gave science as a gift to the people."

Is there anyone on the current scene to replace him - and is it not self-evident that we need not just one Sagan but many, if science is to advance in the popular mind? I know that some scientists have a problem with what they may dismiss as "cheerleaders" and "generalists," but we need such professionals to broker an ongoing exchange between the scientific community and the public. We should therefore encourage the talent for popularization and make room for it in our conception of what a scientist is and does.

A second challenge for the scientific, engineering, and technological community is to work toward a redefinition or even elimination of the attempt to distinguish between basic and applied research. The British biologist Sir Peter Medawar refers to this distinction as both "sinister" and "one of the most damaging forms of snobbism in science." I would add that, in my experience, the most fruitful and rewarding environment is one in which development of theory and application proceed side by side, with ample opportunity for exchange and interaction. Unfortunately, Congressional dialogue about science and technology policy recently has been dominated by concerns about what is "applied," and what is "basic." We need to explain the continuum of research and the parallel paths along which most modern developments proceed.

The third and final challenge for the technological and scientific community is to broaden its commitment to interdisciplinary work. As I have noted throughout this lecture, many of the most exciting and important fields for modern inquiry will require knowledge, insights, and talents drawn from many fields. In determining funding, in granting tenure, and in providing research opportunities, it is vitally important for scientists and engineers not to look at the qualifications and prospects of their colleagues solely in the context of established disciplines. Specialization is important, but work at the interfaces of disciplines, or that integrates across disciplines, increasingly dominates major advances.

If we in the scientific and engineering community can meet these challenges, and if government and industry can play their parts, then we can maintain a fertile and supportive environment for scientific and technological innovation.

I would like to close by suggesting a number of policy goals that we - government, industry, and universities - should pursue:

- As a nation, we must commit to global leadership in research and development;
- We must educate the public and ourselves on the consequences of not doing so;
- We must build and sustain strong federal R&D budgets;
- We must continue to link research and advanced education; and
- We must build new and more productive research partnerships among government, universities, and industry.

These steps are critical to our nation's innovation system and to our future health, military security, economic strength, and quality of life.

By combining these pragmatic steps with the sure knowledge that the end of science is nowhere in sight, we can move toward the future with the confidence that we have provided an environment in which the next generation of engineers and scientists can meet its challenge.

Thank you very much.

QUESTION AND ANSWER SESSION [EDITED]

Q. What can universities do to help improve the Washington political climate toward research funding?

A. I believe that we are starting to make a little headway. I hope that I do not make too big a deal out of this, but it really has been an ideological problem, which goes back to events that some of you in the audience are quite familiar with. Let me give an example, using the Advanced Technology Program of the Department of Commerce as a case in point. This program involved explicit funding for companies working together with universities to conduct R&D in relevant areas which they would otherwise not be able to fund or to undertake.

This program became tagged with the label "corporate welfare," and the discussion soon turned from how to develop partnerships and advance knowledge to a claim that this program was industrial policy, and that as such Republicans in particular should not support it. The interesting thing is that the program was conceived in the Reagan Administration, designed in the Bush Administration, implemented in the Clinton Administration, and supported by large segments of industry.

Unfortunately, this unleashed a whole set of arguments that ended up drawing a big division between applied research, by which many in Congress meant things that industry should be doing, and basic research, which was defined as what universities should be doing. This was really a simple political matter, but the rhetoric so captured and divided people that for two years most of the discussion about R&D in Congress has been about a program that reflects at most a few percent of the R&D budget.

This year has seen the formation of a new bipartisan science and technology caucus, put together primarily by Senators Frist, Republican from Tennessee; Lieberman, Democrat from Connecticut; Rockefeller, Democrat from West Virginia; and Domenici, Republican from New Mexico. More members are now involved, and the group is working very hard to cut through the rhetoric, to pull ideology out of the debate, and, hopefully, to get back to the tradition of bipartisan thinking on and support for R&D. To summarize a lengthy answer, we have been enmeshed in politics rather than in science, and it has been debilitating.

Q. Universities have been sources of knowledge generation and industries have been the places where knowledge has been applied. Is the need now to foster cooperation between universities and industry, and for universities to be more aware of application needs since industry has reduced its role in research?

A. That observation strikes me as correct. As I think about the changes that have taken place in the innovation system over the last decade, they are absolutely congruent with what you have said. By and large, our universities remain very strong, and particularly strong in the core things they do - education and research of a relatively fundamental nature. These should remain the center of what we do. At the risk of being simplistic, industry, and many large companies in particular, has stopped doing much true, long-term or exploratory research. Instead, they have focused on the near term and organized themselves in much more efficient and effective ways. These developments are actually quite exciting. The roles of researcher, designer, and product developer have been woven together in an interesting way that has helped to get many of our companies back to competitive positions in the world economy.

But, as I said to a group of students this morning, the danger is that this system may begin to look like a perpetual motion machine. It's improving, it's getting more effective and efficient, but the question of how new knowledge is fed into the innovation system remains a real challenge. I believe that the center of mass of what we do in universities should obviously remain knowledge generation and education, but somehow we are going to have to cross that gulf. As an engineer - and looking particularly at engineering and management - I think this is providing exciting new opportunities. Industry is not boring these days; it is fast-paced, rapidly changing, and globally interconnected through electronic communications. I think that learning how to deal with that environment, and educating young men and women to go into it, is fun and exciting. It is not something we should be shying away from.

Q. You talked about how industry is reorganized and downsized to become more cost-effective. I wonder if it is not time for universities to examine their operations to become more cost-effective, and thereby be able to survive the proposed cuts in federal funding that are being made in order to achieve a balanced federal budget.

A. The basic answer is yes. I do believe that the tide in Washington, D.C. has turned a bit. As many of you know, as recently as two years ago even Congress was projecting cuts of 20, 25, or even 30 percent in its R&D budget by 2002. I believe it is important that the current estimates are now reduced to eight or nine percent by Congress and by the Administration itself. My guess, and I may be overly optimistic, is that it will be a bit more than that. But no matter how we look at it, budgets are not going to return to the expansionary mode that we all lived with for 20 or 30 years. There are proposals to double the R&D investment over the course of a decade, but even that would not mark a return to the glory days of the late 1950s and 1960s.

I believe that we do have to work to make our educational institutions more effective, more efficient, and more cost-effective. I do not know what you have been through, but as some of you with MIT backgrounds know, we are about two years into a process of substantial re-engineering (restructuring) of the ways in which we provide support services and infrastructure. We have downsized by several hundred employees over the last few years. We are trying to put in place more effective business systems, doing many of the things that American companies went through about five years before we did. It's not fun, it's tough. But you do learn as you go that there are things that you can do better.

In the educational process itself I have greater difficulty thinking about what leading institutions like Georgia Tech and MIT should do in terms of cost-effectiveness. Overall, I believe strongly that the use of information technologies, the sharing of resources through mechanisms like the World Wide Web, and distance learning are going to play an important part in learning. I don't believe technology will or should replace the residential university experience, however, so we will have to work continually at this. We cannot have the cost of education continue to grow at the rate it has been. I think we all need to think carefully and perhaps radically about how to make the changes you suggest. It is not an easy problem.

With apologies to a few of you with whom I spoke earlier today, when we talk about the quality of education and why tuition is higher at some schools than at others, the first measure we usually think of is the ratio of faculty to students. I think there are a lot of things we can do to teach fewer highly specialized individual subjects by clustering disciplines in different ways to teach more effectively. I don't believe it is an easy problem, but we should not be sitting back saying that all this is going to pass, that the federal government is going to change course and provide for exponential growth.

Q. Given that research and development investments help the economy in the long run, how can we determine how much the country or a company should invest in research and development?

A. I think the question of how much is enough is the most difficult one of all to think about. In fact, my colleague Harold Shapiro of Princeton (a brilliant economist) set two or three graduate students to answer that question a few years ago, and they never really succeeded. What can you look at as tips?

First of all, I don't like to argue in such a utilitarian fashion. In all the public communication I do on the importance of science and technology, particularly with the federal government, I keep emphasizing the importance of education, fundamental inquiry, and the generation of new knowledge. Our value to practical concerns like health, economic productivity, and national security accrues ultimately from our readiness to explore the unknown.

There is, of course, a strong economic incentive for investing in education and research. The Economics Department of BankBoston just completed a study that tried to measure in some simple way what the economic impact of MIT graduates has been. Through very careful surveys and studies, they concluded that MIT graduates have founded over 4,000 companies operating today. Those companies employ 1.1 million people, and if their revenues were looked at like a nation, they would be 24th among countries in gross domestic product. That simple headline captures the essence of what most of those in Congress today find the most compelling argument. Increasing people's knowledge, understanding, and skills in the end creates jobs, wealth, and improves society. I believe that deeply.

Does that mean we should put two and a half or seven percent of the GDP into R&D? I don't know. We are clearly underinvesting now, at 2.4 percent of GDP. Many people have looked at this, including the Clinton Administration in its first term, and have concluded that somewhere around three percent of GDP invested in real R&D would probably be a reasonable figure. Another way to look at it is to examine what companies in various sectors have to invest in order to maintain their innovation and competitiveness. There you find figures ranging from two percent to as much as twenty to thirty percent, so I don't know the answer to the question in reality. But when asked a number of times in Congressional hearings to make a pragmatic suggestion, I have tended to respond that if those budgets were to grow perhaps a couple of percentage points more quickly than inflation, so that we maintained some steady, gradual growth, we would probably be in an improved position.

A final example, to provide a figure at the opposite extreme, is Japan. Japan currently spends as much on nonmilitary R&D as the United States does: not per capita, not normalized, but absolutely. Second, the Japanese federal government has mandated a doubling of their rate of expenditure by shortly after the turn of the century. I am told by my colleagues there that they will not quite make that. But in areas of strategic importance their budgets are growing at ten percent per year, and have been for some time. Southeast Asian countries, such as Taiwan and Singapore, are dramatically increasing their investments in education and R&D. We should be doing more. First, we must improve education in grades K through 12; second, we must invest more. I hope this gives some feel for an answer, but this is not an easy question.

Q. If we keep increasing the investment in engineering research and education, aren't you concerned about simply running out of people who want an engineering education?

A. Well, that would be rather the absurd way of answering the question, how much is enough? But you have a very serious point. I would like to respond to it in two ways.

Those of you who were faculty and administrators twenty years ago will remember that we all sat around looking at curves showing the country's birth rate and immigration statistics. Over the course of twenty-five years or so, the number of eighteen and nineteen-year-olds in this country dropped dramatically - between twenty and twenty-five percent. Everyone believed that colleges and universities would be going out of business left and right. What happened instead was that as we crossed that minimum point, about two years ago, college enrollment went up. What happened? Simply, we broadened the net of people we teach, not at places like Georgia Tech but at other colleges throughout the country. Vast numbers of women came back to get more education to better their place in the workforce, and nontraditional students began to come, at different ages. If our goal were simply to fill up universities, it would be absurd. But that is not at all the point. I think that those people who have the talents, the ability, and the drive to come to a place like Georgia Tech or MIT should have the opportunity to develop their talents or skills.

Our problem now, in my view, is that we are all wasting time competing for modest resources. Many faculty members in science and engineering fields are spending far too much time writing proposals and administering grants, in order to keep a reasonable level of support. So I think there is room to get back on at least a normalized basis to someplace more like where we were a decade or fifteen years ago. We have got to remain ahead of inflation.

ANNOUNCEMENT

The 1998
George W. Woodruff
Distinguished Lecture

Thursday, April 23, 1998, 3:30 p.m.
Van Leer (EE) Auditorium
Georgia Institute of Technology

Robert A. Lutz

Vice Chairman, Chrysler Corporation

Robert A. Lutz was named Vice Chairman of Chrysler Corporation on December 5, 1996. Lutz is a director of the Company and focuses primarily on product development activities. As a member of the Office of the Chairman, he is involved in all major decisions. Prior to this position, Lutz was President and Chief Operating Officer, responsible for car and truck operations worldwide. Lutz joined Chrysler in June 1986 as Executive Vice President.

Prior to Chrysler, Lutz spent 12 years at Ford Motor Company, where he was Executive Vice President of Truck Operations, Chairman of Ford of Europe, and Executive Vice President of Ford's International Operations. He was a member of Ford's Board of Directors from 1982 to 1986.

Lutz started his automotive career at General Motors Corporation, where he held a variety of senior positions in Europe. Later, he spent three years as Executive Vice President of Sales at BMW.

Lutz is a member of the Board of Directors of Northrop Grumman, ASCOM, a Swiss telecommunications and electronics company, and Silicon Graphics, Inc. He is also a member of the American Highway Users Alliance, the Advisory Board of the Walter A. Haas School of Business at the University of California, Berkeley, the executive committee of the National Association of Manufacturers, the board of trustees of the U.S. Marine Corps University Foundation, and a trustee of the Michigan Cancer Foundation.

Lutz received a B.S. in 1961 and an M.B.A. in 1962, both from the University of California, Berkeley. He was born in Zurich, Switzerland.

The George W. Woodruff School of Mechanical Engineering is the oldest and second largest of eight divisions of the College of Engineering at Georgia Tech. The School offers academic and research programs in mechanical engineering, nuclear and radiological engineering, and health physics.

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