28 Science, Technology, and Innovation: Reflections on Change

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The context for science and technology policy is rapidly changing. Increasingly, we must think of it in terms of a global innovation system. This system is a chain of events that runs from the generation of new knowledge to the education of young men and women to do things with that knowledge, and ultimately, to the creation of new products, processes, and services in the commercial workplace.

My comments on this topic are divided into three parts: a few fables, a few observations, and some comments on the changing role of our research universities.

Fables

The first fable is titled "Racing to Sequence the Human Genome." We suddenly are in this rather strange race. On one hand is a group put together as an international collaboration of governments and a charitable trust (the Wellcome Trust, which supports public institutions such as Washington University, the Massachusetts Institute of Technology (MIT) Whitehead Institute, Baylor College of Medicine, the Sanger Center, and U.S. Department of Energy laboratories). They are working together to see how quickly they can come to a consensus sequencing of the human genome, and thus make their sequence fully available to anyone who wants this as they proceed. But they are racing against for-profit companies and organizations, such as Celera and Gensat. The

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bait in this race is a concern about how elements of the human genome might, in fact, become patented. (Of course, it is actually more complicated than this. A consortium of ten pharmaceutical companies also supports the public side). The argument can be described as whether you patent the dictionary or put the dictionary out there as a free good for use by everybody and worry about patents for the people who write the novels. The moral I draw from this fable is that we are rebalancing public and private responsibilities. This is just one example.

My next fable is titled "International Entanglements." I recently had a telephone conversation with the CEO of a major company, whom I respect very deeply and whose company is headquartered in the United States. The gist of the conversation was that he and his colleagues were not happy with the extent of MIT's technological collaborations with companies and, in some cases, even government entities outside the United States. It was not a hard push against us, but it was, indeed, a clear statement that they would be happier if we focused more on working with companies headquartered in the United States. This is not a new complaint, but it has not been very prominent since the balance between the United States and Japanese economies has changed rather dramatically during the last five years. I certainly did not totally agree with his perspective, however.

The very next day his Vice President for Research gave a speech in which he outlined that same company's strategies for locating R&D laboratories overseas in partnership with foreign universities. They are not alone in doing this. This is yet another important trend that we all need to be aware of and understand.

Many companies headquartered in the United States are increasingly performing some of their R&D functions offshore for several reasons. Generally, they want to help build local expertise. In some cases they even talk about creating the "world engineer," able to practice in any region of the world. They need access to differing cultural norms that may affect research and development functions. Way down the list is that some work can be done at a lower cost overseas. Of course, all of this drives the development of new customer bases for their products.

The Council on Competitiveness investigated this phenomenon in some detail and produced a report titled "Going Global." One of the things they discovered is that while a substantial amount of corporate R&D is moving offshore, apparently very little innovation that makes it into products is coming through offshore R&D. This raises the question of whether the movement of R&D offshore is a permanent or tem-

porary trend. Whatever views we may have, we must work together to understand and consider the way in which we perform technological R&D on an international scale. (Fundamental science, of course, is international to the core of its very being. Here I am referring more to industrial applications).

The moral here is simply that we have not made up our minds about national versus global roles. This issue is going to be in a state of flux for some time.

Another fable is titled "Some Horses Want to Be Led to Water." This is actually good news. Congress recently established a group called "The Technology and Innovation Forum," or Tech Forum for short. This group was the brainchild of Senators John D. Rockefeller (D-WV) and Bill Frist (R-TN).

Senator Rockefeller reasoned that Senators and Representatives do not come to hearings on the future of R&D because they do not know what questions to ask and they do not want to embarrass themselves. This was also the situation several years ago in the area of health care. To address this situation, Senator Rockefeller established an informal bipartisan forum to increase Congressional understanding of the fundamental issues facing the U.S. health care system. They provided free bag lunches and brought in interesting expert speakers. The first time five or six staffers came, the next time 10 or 20, and a few years later typically 100-200 people came to these forums. Interestingly, the new Technology Forum has attracted this level of participants from its first meeting onward.

As senators and representatives came to understand the importance and complexity of health care issues, they began to hire staff with relevant health care expertise, and Congressional work on health care improved significantly. Senator Rockefeller believes there is a similar situation today regarding science and technology in the House and Senate. Note that many members of Congress, including himself, became more interested in S&T issues when they had AAAS fellows in their offices. As they began to learn more, some hired full-time staff who had expertise in the area.

It will take time to build Congressional expertise that matches what both of these senators believe is a very strong thirst for knowledge about science and technology within the membership of the House and Senate. This is the goal of the Technology Forum. So my moral to this fable is a very simple one: We need to better explain what we do, why we

do it, and how we do it. We have a willing audience if we approach them in the right way.

Observations

I now want to offer a few additional observations The first stems from the following question: Why would the chambers of commerce across the United States orchestrate a letter-writing campaign supporting OMB Circular A-110? The issue has to do with access to fundamental data underlying any scientific research that is used to create federal policy or regulation. Last fall, during the authorization process, legislation was enacted to require that all such data be accessible to the general public through the Freedom of Information Act. The legislation required that the Office of Management and Budget translate this into regulatory language and implement it under OMB A-110.

The scientific and engineering community was a bit slow to respond, but respond it did with broad concern that considerable mischief could stem from such a regulation. The basic issues are fairly obvious. One is simply the daunting thought of having raw scientific data suddenly accessible without having passed through the normal routines of peer review and being communicated in a careful manner. There are also deep issues about personal privacy, particularly in medically related research.

Ironically, at the same time that many in the business community see A-110 as a way to gain access to research, such regulations could provide a disincentive for industry to work with universities. For example, MIT has two major research programs in which we follow about 20 companies, sharing data on their design process and how they translate designs into manufacturing practice. These are real trade secrets. Our role is to be the honest broker within a framework that all agree to. In this framework, we take the data, create a database, and give information back to people so they can understand best practice and evaluate their own work, all without giving away trade secrets. Government sponsorship is involved in at least one of the programs.

Many unintended consequences could obviously stem from the current version of A-110. But while we are pointing out the flaws and the possible inadvertent negative consequences, we also have to be reasonable and recognize that we do have a responsibility to the taxpayers and the government that supports our work to provide appropriate access to all we do. It is not a simple problem, and it does not have a simple

solution. We need to make our voices heard as AAAS and many other organizations have done.

Another observation: We continually talk about the ubiquity of information technology and note that it is changing the way we all live, learn, work, and entertain ourselves. But who is "we"? Only about two percent of the world's population has access to the Internet. About 29 percent of the people in the United States and Canada are linked to the Internet, and about five percent of Europeans are. Anywhere else on the globe the number is less than one percent. We need to understand the dangers of creating a new kind of "have" and "have not" on the international scale. Those people involved in the development of information technology and its applications need to direct some attention to the lesser-developed nations and consider the appropriate development of information technology in this context. I hope we can find many positive ways of dealing with this. (In Costa Rica, for example, they are using modern telecommunications to dramatically improve access to information as well as to improve education. They are also using it to enhance environmental awareness and a very deep commitment to the concept of sustainable development).

Another random observation I call "Seeking Balance." Senator Arlen Specter (R-PA) called the proposed increases in NIH funding "a moral imperative." This is strong language, and very welcome. Both basic and applied research in life sciences are extremely important for the future. But we have to balance that against another imperative: the interconnectedness of science. This has been recognized by Vice President Gore and his colleagues in the Administration, particularly in the 1998 announcement of the Administration's R&D budget. This is an important message. We have a responsibility, whether we are life scientists, engineers, physicists, or mathematicians, to keep people aware of the way in which our different disciplines interact. The race to sequence the genome is an example. That, of course, involves biology, by definition. But, in fact, clever use of combinatorial mathematics, robotics, engineering, and automation is making the whole venture possible. We never know exactly what the next most important advance will be or where it will come from.

My next observation is actually a question: As we think about American innovation and entrepreneurship, should we think of ourselves in the United States (or even around the world) as a number of clusters, localities, cities, and states, or should we think of ourselves in a more common framework? For years this debate has generally been around

discussions of Route 128 in the Boston area and of Silicon Valley in northern California. We often hear questions about how such clusters can be replicated in other states, cities, or districts.

Scholars such as Michael Porter at Harvard write quite convincingly about the importance of creating local clusters of expertise around a particular industry in order to gain a competitive advantage. In addition to the two well-established ends of the axis, Route 128 and Silicon Valley, other clusters are emerging. Consider the Georgia Alliance or work going on in wireless communication in the San Diego area, or Pennsylvania, or Austin, Texas, or in the District of Columbia. Increasingly this local cluster phenomenon and point of view is taking hold. It is very positive and it stems from strong public spirit and commitment. It comes from new organizations getting different sectors to work together to advance economic development.

But Regis McKenna, a great venture capitalist who is one of the fathers, as it were, of the Silicon Valley revolution, has said, "I think these things are being absolutely overstated and it is the wrong perspective. This is a modern network world. We should not think of ourselves as isolated clusters. We are all nodes on a great network and we should think about being able to interact all over that network. In the end that will serve this country much better."

At a recent meeting in Michigan, the question was how to make that state as strong as possible economically in the new technological fields. A person who runs a small biotech company stood up and said, "I'm going to partner with whoever has the expertise I need to provide the best possible product and gain the greatest advantage. I don't care where they're located." Again, I point this out as an observation, not as a conclusion. It is something we all need to think about in our day-to-day work.

This issue leads to one last observation: Industry today, as we say over and over, is increasingly knowledge-based. It is global, and driven by innovation. It is digitally interconnected and created by entrepreneurs. I would like to consider the implications of this for our research universities in particular. Our research universities generate much of the knowledge that drives modern industry, and even more important, they educate the men and women who work in these industries.

Knowledge-based industry reminds us that basic research within our universities is needed more than ever because we are increasingly the only game in town when it comes to the creation of truly fundamental knowledge. We may not know where such knowledge will lead, but it has some likelihood of being used, whether two years from now or 100 years from

now. I hope our system of financing research and our culture will always support first and foremost the conduct of truly basic research within our institutions.

The Changing Role of Universities

We in universities have many things to think about. What does globalization mean for our institutions? To what extent should we engage in partnerships, particularly those that cross national boundaries? What linkages should we develop with other universities and perhaps with other countries and companies? Above all, what does it mean for our curriculum? Do we have a responsibility to our students to somehow represent globalization in our curricula?

What about innovation-driven industry? What is the source of innovation? Our universities must be an important part of the chain of innovation, both in the creation of new knowledge and ideas and in the education of people. Do we need to recognize this more explicitly? Again, should it be reflected more in curricular development—and who should be part of that process?

We play a role in developing information technologies. What does that have to do with our curriculum? Is our responsibility to broadly educate people about information technology or to create more specialists?

And, finally, how do we respond to the pervasive phenomenon of entrepreneurship? Universities are trying to respond by creating entrepreneur clubs, contests, etc. People are starting companies in the first two or three years out of college, or sometimes while they are still in college. How much can you intellectualize this? What part of the responsibility for creating entrepreneurs does or does not lie with our institutions?

Universities are tugged and pulled by all these changes and questions. On the one hand, we need to work much more than we have with industry on fast-paced real-world projects. We have to do that if our faculty are to be able to provide up-to-date engineering and management curricula and experiences that will serve our students well. Simultaneously, we are being pulled in the other direction because we are literally the only basic research game left in town. We have to play both ends. Those institutions that succeed in doing both with a level of mutual respect and cooperation will be the strongest and will provide the best education, particularly for their engineering and management students.

Universities are, in fact, changing. We are conservative institutions because we have a lot of things that are very important to conserve.

Nonetheless, there are a number of changes underway that we may not even recognize today, but that will have profound consequences. They are the result of several trends.

First, we see changes in our finances. I speak, of course, primarily as a representative of a private institution that is predominately devoted to science and engineering. Endowments are up for private universities, which have benefited enormously from the increase in the stock market over the past five years. This is particularly fortunate because our federal support is leveling off. (If you look at most institutions on the surface, at least, our federal support is up a little bit. In a few places it is up dramatically. But, for the most part, particularly outside the life sciences, it is level to slightly up, but it is delivered with increasingly difficult cost-reimbursement policies attached).

The federal funding profile is also changing through dramatic growth in the NIH budget, which is understandable and sensible from many dimensions. We should keep pushing for this, but other agencies are growing much more modestly or declining. We hear calls from within Congress to double research funding but they all come with different time lines attached. Doubling in five years is a very different matter from doubling in twelve.

But there is good news, such as the increase in private support that has come with the strong economy. The economy also helps the tax base in our states and thus our public universities. But we have to face the fact that the fundamental laws of economics have not been repealed. We will ultimately have turbulence. We have already seen substantial volatility in the world economy.

More good news is that the tone in Washington is increasingly supportive of our institutions in a way that is much, much better than it was just a few years ago. But, of course, traditional political forces are always at work and we will always have to deal with them.

Other areas of change revolve around three new themes, three words frequently heard around research universities today. They are *innovation*, *partnership*, and *entrepreneurship*. We are increasingly recognizing that our university research is a critical element in America's innovation system. And we are increasingly looking to partnerships with other sectors (industry and government) and discovering new ways to work together in research and education. I think we are going to find dramatically successful partnerships in the years ahead. And we have to think through the proper role of entrepreneurship in the university context.

Technology is changing within our institutions, making innovation an exciting theme. New bases of science are beginning to undergird a variety of branches of engineering. For many years engineering has helped those in the life sciences, by creating instrumentation for example. We are now entering an era in which that flow is going to reverse. We will see a tremendous flowering of engineering capabilities based on all the developments in cell and molecular biology and other areas of the life sciences—particularly in the creation of new materials. (And I hope these methods will use less energy and create less waste).

We also see an increasing involvement of engineers in the academy in thinking about very large complex systems, whether it be the logistics of transportation or the complexity of electronic circuitry and networks. Large complex systems is a pervasive theme, as is so-called embedded intelligence. The integration of microprocessors in virtually every kind of mechanical device and element today is creating wonderful opportunities for advanced engineering research. We are beginning to move to the next generation where these various intelligent elements and systems interact with one another in new and different ways. It is going to be very exciting.

Finally, we are seeing a swing in the balance of experimentation and theory. As I look over the past 20 or 30 years, new advances, instrumentation, and capabilities have led to a movement back to lots of experimental work in addition to theory and computation.

But the more interesting and in some ways more profound changes have to do with people. The demographics of college-age young people in the United States are changing very rapidly. We are seeing increases in our minority populations. We also see, at long last, an increase in the number of women going into science and engineering. (This year's freshman class at MIT is 43 percent women. Since 85 percent of our students are in scientific or engineering fields, this is very significant). Add to this the increase in the number of international students, and first- and second-generation immigrants. Unfortunately, at the same time we continue to see an overall decline in the percentage of young Americans interested in science and engineering. That does not bode well for the future.

We are seeing dramatically changing career paths of science and engineering graduates. More and more students are moving into the service sector, finance, consulting, and so forth right out of science and engineering school. A recent survey found that 35 percent of recent engineering graduates have jobs completely "unrelated" to science and

engineering (whatever "unrelated" means). In MIT's graduating classes in the late 1960s and early 1970s, two-thirds went directly into Ph.D. programs in a science or engineering discipline. Now that is a much smaller portion.

This is, of course, a reflection of changing student interests. We see an acceleration of interest in the life sciences, environmental matters, management, and economics (perhaps combined with science or engineering). For the last eight years or so, the number of students going into computer science and engineering has been diminishing. At MIT, though, over 20 percent of our incoming freshmen intend to go into computer science. But the national trend seems to be different.

Of course, there are changes in our faculty as well. A recent report by a committee of very distinguished MIT faculty members looked at the experiences, careers, and views of the senior, tenured women in our School of Science faculty. We learned some things that were not very pleasant, and we have begun working hard to correct them. Basically, we learned that our distinguished women faculty in the School of Science found themselves feeling increasingly marginalized, rather than gaining in stature, as they moved into the senior ranks. But what absolutely astounded me was the national resonance to the release of this report. I could not begin to describe the traffic of letters, e-mails, press, and editorials we have received. Most of the comments were positive about our articulating these things and facing up to them.

Another area of change is the increase in international initiatives and strategic collaborations. One example is the Association of Pacific Rim Universities (APRU) formed by Asian and Western U.S. universities. The exporting or perhaps re-exporting of the U.S. research university overseas, particularly to Europe and Asia, is extremely interesting. Government after government, city after city are coming to various public and private institutions around our country asking us to help them create U.S.-style research university institutions in their countries. Much of this, of course, involves large-scale experiments in distance learning, using technology between the U.S. and other countries. Despite all the exciting things we are going to do with new technologies and distance learning, I believe that the residential campus is going to remain uniquely important in the education of the very best and brightest young men and women.

Congressional and public support is much stronger than it was just five or six years ago, helping us to slowly but surely implement change. This is a very important time to undertake a variety of educational ex-

periments in these changing contexts and to share the results of these experiments among our institutions so we can all improve. Of course, beneath all of this are the daunting problems in primary and secondary education—problems that simply must be addressed in this country. (Let us never forget that without education none of the innovation and economic development we celebrate can exist or moves forward). This is a time of great adventure, challenge and, of course, uncertainty.

Finally, let me comment briefly on science and technology policy. Technology continues to advance in exciting ways but it does so within a context in which the relationships among public, private, and academic institutions seem to be changing and becoming increasingly amorphous. Anything we call science and technology policy today must involve an understanding of both the public and private sectors. There was a time in which science policy indeed referred only to *science*. In fact, if you go back far enough, it essentially meant only physics. And it was entirely within the context of the federal government. We must now think broadly about both the public and private sectors. We must remember that innovation and economic development involve research, development, and business.

Another major message, which I hope our Tech Forum can help spread in Congress, is that technology means more than just information technology. It is astounding how many people today think about only that one dimension when you say "technology."

The scientific decades ahead will be fantastic. We will discover whether there are antimatter galaxies out there. We will have tremendous advances in neuroscience and brain research. We are going to learn how to manufacture materials in a greener way, with lower energy input. Whole new areas of biodiversity are going to take us along very different scientific routes and adventures. Where the Genome Project will ultimately lead, no one knows. The capabilities of truly advanced large-scale simulation are going to give us a third way of doing scientific and technological inquiry complementing experimentation and analysis. The fundamental nature of computing and what it means is also going to change radically in the decade or two ahead.

Finally, this new age—where science and technology are changing the way we do virtually everything—will bring with it many difficult ethical questions. In my own institution I do not believe we expose our students to enough of this dialogue. I hope that in public life as well as in institutional life, we can reflect more on what we do, why we do it, and how it fits into an ethical framework as we move forward.