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FIVE YEARS OF THE AMERICA COMPETES ACT: PROGRESS, CHALLENGES, AND NEXT STEPS

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED TWELFTH CONGRESS

SECOND SESSION

SEPTEMBER 19, 2012

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED TWELFTH CONGRESS

SECOND SESSION

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FIVE YEARS OF THE AMERICA COMPETES ACT: PROGRESS, CHALLENGES, AND NEXT STEPS

WEDNESDAY, SEPTEMBER 19, 2012

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 2:37 p.m. in room SR–253, Russell Senate Office Building, Hon. John D. Rockefeller IV, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. JOHN D. ROCKEFELLER IV, U.S. SENATOR FROM WEST VIRGINIA

The CHAIRMAN. Hi, we are a little late, we had a vote. Actually, it was a pretty important vote that we should get bridged through March, and the nation will not collapse right away.

Before I begin, this is probably Kay Bailey Hutchinson's, that is this good lady's, last hearing as United States Senator. And, I have six pages which I am not going to read about her, because my statement is also quite long, my opening statement.

But, let me just say that we, together, have had about 177 hearings, we have had 28 markups, and we put 100 bills out of this Committee. That does not mean they have all passed, but they have all gone to the floor, and there is no way for me to describe the smarts, the toughness, the tactical instinct, strategic intuitions, and the tenacity that Kay Bailey Hutchinson has.

I am a Democrat. She is a Republican. It does not make any difference. We made this Committee, for the first time that I can remember, into really a bipartisan Committee. I will admit you would not know that as you look around today. We have one very nice person over here, and I am waiting for some other people to come. But, it is a bipartisan Committee, and it is known as such. We are known as a Committee which gets stuff done, and puts out legislation. A large reason for that is Kay Bailey Hutchinson, and, I for one am going to be incredibly sorry to see her go, not only as a friend, but as a professional.

For example, the bill that we are working on today, America COMPETES, could not have happened without Kay Bailey Hutchinson. There are a lot of folks on her side who were very recalcitrant, and she set about to one-by-one horse-collar them and shake some sense into their heads, and it ended up passing by unanimous consent.

Now I have short-circuited all of the facts just a bit on that, but the fact is she worked really hard, because when she believes in something, she works really hard to get that something.

She feels the same way about the transportation bill, and we worked well together on that. That was a huge bill, not necessarily to the American public, but it will be when those projects are done. We also did the Federal Aviation Administration bill, and she is an expert in aviation, being a trained lawyer, and very experienced in all of these things.

And, there were points in the FAA bill, well, we had a funny little thing called a slots problem. And to the average person out in America that is the most important problem that has ever been brought to the face of the earth. If you live in San Francisco, or you live in Los Angeles, or in Portland, or you know, in Seattle, and you get one flight a day from D.C. Airport, Reagan Airport, out to that airport, and one flight back that day, you think that is really dissing the west, and it is.

And, we have had folks on our side who come from the east who want to protect the status quo. You know the growth of the population is in the west, and the southwest. And so, the question of getting people, who did not want to yield more slots, that is opportunities for coming and going flights for various airlines at Reagan Airport, became a very big deal because people need to come here, and we found a solution. And again, a lot of that was because of the knowledge and the really ferocious lobbying that Kay Bailey Hutchinson did.

I mean, she is a very nice lady. I do not want to make her unladylike, but she is ferocious when she wants something, and that is important in this business.

So, Kay Bailey Hutchinson, let me just tell you that I am very, very sad that you are leaving, and actually let this be on the record. She is the only Ranking Member, or if I were a Ranking Member, Chairman, that I have ever sent flowers to on Mother's Day. Now, explain that. On the face of that it makes me look pretty serious, but I wanted to do it, because I was grateful for what she had been doing, and continues to do. So, Kay Bailey, you just have to accept this thing I have laid upon you.

NASA, do not get in the way of Kay Bailey Hutchinson on NASA. Well then you got to watch out for both Kay Bailey and Bill Nelson with different interests, right?

Senator HUTCHINSON. No.

The CHAIRMAN. Well, to some extent. To some extent, you each got about 200,000 jobs, right?

Senator HUTCHINSON. We both support the same thing. America's preeminence and manned space exploration.

The CHAIRMAN. Well, you see she is cerebral. Anyway, I do not know what you are going to do next, but I do know that it will be important, and I know it will be done well, and I know that we will miss you very, very much.

Now, let me go onto our business today. It has been just over 5 years since the original America COMPETES Act became law, and less than 2 years since the reauthorization was enacted.

Hi, Norman, how are you? I have known you quite a long time, and see you very little. Does not matter, you are very good.

Both COMPETES Acts have focused on basically three main goals.

Number one, increasing science and research investments. Number two, strengthening science, technology, engineering and mathematics, STEM education, where our record may be uneven, and developing an innovation infrastructure. These are inherently all long-term investments.

People expect that when you pass something that has quite a lot of money in it that you are going to see engineers and masters just flying out of schools, and colleges, and graduate schools, and it does not unfortunately work like that. So, not enough time has really passed to get the full impact of our 2010 bill.

Larry Page and Sergey Brin's original research that led to Google was initiated with a National Science Foundation grant in 1994. And, that was nice.

Back in the days when they just did individuals [EPSCoR grants] as opposed to institutions with infrastructure. And, that was a conversation that Erich Bloch and I had to have at some length. Because he liked the old way and I liked the different way, and eventually with Robert C. Byrd joining in, we got our way, and {EPSCoR] has been better because of that. So now, colleges and universities all over rural states and urban states are getting opportunities for particularly golden nuggets of research that are being done there to be able to allow that to go forward.

So, the National Science Foundation did that for Google in 1994. Google did not go public until 2004. Their small share of $4.5 million National Science Foundation grant led to a company that today has $200 billion plus, over 50,000 employees. So, success takes time.

Even with these unknowns, we still must take time to understand where we are, and what we must do next, which is why we are here today, and thankfully you are here.

The 2007 Act authorized a doubling of funding for the National Science Foundation, major research accounts at the National Institute of Standard and Technology, and the Department of Energy's Office of Science, within seven years.

Unfortunately, Congress did not follow its own direction, with appropriation slowing the doubling period down to 15 years. OK, well that is better than 25.

The 2010 reauthorization attempted to find some middle ground rule with an 11-year doubling path, but again the appropriations and the President's request levels have not followed, pushing the doubling out to 18 years.

Without full support for these programs, we are doing our very best to create a disservice for our economic recovery. Losing our dominance in science and high-tech fields has led to a loss of 687,000 manufacturing jobs since 2000. For example, our global share of global high-tech exports has fallen from 22 percent in 1998 to 15 percent in 2010.

Unemployment rates for STEM occupations trend lower than those for all college educated individuals, and they earned 26 percent more on average. So, there it is, what an opportunity, and where are the people to take advantage of it? Huge problem. That is what America COMPETES is for.

Despite this, our 15-year-olds score lower than the international average in mathematics and science, and you know all of that.

We heard, in March, from representatives of several of our major Federal science agencies and coordinators. And, today's hearing is a continuation of that conversation.

To start we have Mr. Norman Augustine, who is the former CEO and Chairman of Lockheed Martin. Mr. Augustine chaired the 2005 National Academy of Science report "Rising Above the Gathering Storm" that helped push Congress toward passage of the original America COMPETES Act.

We also have Dr. Carl Wieman, is that right?

Mr. WIEMAN. Wieman.

The CHAIRMAN. Wieman, darn, I apologize. Before the Committee again today. Dr. Wieman came before us, this Committee, during the nomination to be Associate Director of the Science of Office and Science Technology Policiy (OSTP). He served the Nation well, before stepping down earlier this year. He is a Nobel laureate in physics, and he is a strong proponent of science and technology education. We are glad you are here, sir.

Dr. Jeff Furman, the same, we are glad you are here, an Associate Professor of Strategy and Innovation at Boston University and Research Associate with the National Bureau of Economic Research.

Dr. Peter Lee joins us today from Microsoft Research Redmond Laboratory, which he leads in the search for disruptive business innovation—excellent phraseology.

Mr. John Winn, Chief Program Officer of the National Math and Science Initiative joins us as well today. Mr. Winn has over 35 years of STEM education experience. So, we may have some things that we want to ask you.

I now turn to my distinguished, lauded——

STATEMENT OF HON. AMY KLOBUCHAR, U.S. SENATOR FROM MINNESOTA

Senator KLOBUCHAR. Mr. Chairman, Mr. Chairman, I have to go preside over the Senate. So, I was just going to put my opening statement on the record, and also just commend Senator Hutchinson for her great work on the Committee and join you in your comments. She has been amazing.

I was talking to some of our auto dealers last week and they remembered the work that we did, and so many, just so you know, in Minnesota, 1,700 jobs were preserved, and I do not think it would have happened without you and all of these great things you have done for the country, and I have loved working with you, and I know we will talk more about it on the floor at the end of the year. But, thank you for your service on the Committee.

Senator HUTCHINSON. Thank you very much. Thank you.

[The prepared statement of Senator Klobuchar follows:]

PREPARED STATEMENT OF HON. AMY KLOBUCHAR, U.S. SENATOR FROM MINNESOTA

Thank you, Senator Rockefeller, for holding this hearing, and thank you to our witnesses for being here today.

I was a co-sponsor of the original COMPETES Act and continue to support its mission and goals, which are critical to strengthening our economy and keeping our country competitive on the world state.

We know a thing or two about innovation in Minnesota, the state that brought the world everything from the pacemaker to the post-it-note to the pop-up toaster. We're also second per capita for Fortune 500 companies and home to some of the world's most innovative businesses, like 3M, Medtronic and General Mills.

Minnesota's economy is doing better than the rest of the country, with our unemployment more than two points above the national average, because we are committed to innovation and bring our technological advances to the marketplace.

In today's increasingly competitive global economy, this is where our focus needs to be as a nation. We can no longer afford to be a country that just churns money around on Wall Street. What we need to be now is a country that makes things again. . .be a country with a competitive edge. . .a country that thinks, that invents, and that exports to the world.

There are a lot of really important policies in the American COMPETES Act that are helping us get back to those brass tacks and that's why I'm so glad we're holding this hearing today.

As you know, I also chair the Subcommittee on Competitiveness, Innovation, and Export Promotion subcommittee, where I've been focused on a lot of these issues myself.

I believe we need to be building an innovation agenda for America—a competitive agenda that can build off of the COMPETES Act and get our economy moving again.

Amongst other things, this calls for a renewed focus on exporting, so that more of our businesses can reach the 95 percent of world customers who live outside our borders.

This calls for a better system for commercializing university research, so that the next pacemaker or post-it-note isn't just collecting dust on a laboratory shelf somewhere.

This calls for an increased emphasis on STEM education—the critical science, technology, engineering, and math courses that are essential to innovation.

In a 2009 study, the United States ranked 25th out of 34 countries in science and math education, behind countries like China, South Korea, and Finland. We must do better.

If we're going to maintain our competitive edge and innovate our way to the top, we'll need to be proactive—and not just reactive.

We'll need to better equip American students and workers with the skills and training they need to succeed in the job market.

This was the thinking behind the Innovate America Act, a bipartisan bill that I introduced last year. It focuses on turning the research that comes out of our universities into the products that will grow small business and create jobs. It also rewards community and technical colleges that strengthen their STEM offerings, so that our students have the tools to do the jobs in today's economy.

Our Universities and Community Colleges are critical partners in driving entrepreneurship and innovation. The not only train the workers that drive our industry, but the research that leads to new products and technologies.

Research isn't just an academic pursuit—it is an economic catalyst. By some accounts, R&D generated 50 percent of our nation's economic growth between 1950 and 1993.

And a majority of that research and development took place in the university system, which has long been an incubator for startup businesses. It is our job to support these innovators and entrepreneurs that bring these products to market and create jobs for Americans.

And it's not just our four year colleges that are leading the way:

Whether it's the University of Minnesota developing solar thermochemical reactors and other alternative energy research under America COMPETES Act programs, or our local community colleges like Dakota County Technical College, which has received NSF STEM funds for the past two years to encourage retention, training, and placement in STEM jobs, these programs will help get local workers into local jobs. We need to continue to support this competitive agenda.

In today's economy, standing still is falling behind. We must commit to moving forward. That's why today's hearing is so important. As I said before, I co-sponsored the original COMPETES Act and I continue to support it today.

But we want to be sure it is as successful and effective as possible and that's why we're here today—to evaluate the program, discuss ways to build on its progress and make changes where necessary.

I look forward to hearing from today's witnesses and getting some good ideas for moving forward. Thank you.

The CHAIRMAN. And, your statement is in the record.

Senator KLOBUCHAR. Thank you.

STATEMENT OF HON. KAY BAILEY HUTCHISON, U.S. SENATOR FROM TEXAS

Senator HUTCHINSON. Thank you. Well, Mr. Chairman, I have to say this is a nostalgic time for me as well, and I cannot think of a better partner to have than you, and I think that you and I really have done some major things.

You talk about 100 bills that have passed out, but we have done some really big things, and I do not think there has been any time when we have not been able to put together our differences and go forward in a productive way, and get a movement in a major field.

So, I will not send you flowers, but I do want to throw bouquets, and say that you have been a joy to work with.

I am just going to reiterate a few of those accomplishments, before I go onto to talk about America COMPETES, because America COMPETES is one of those things of which I am most proud. I think it did make a statement from Congress at a time when people were saying Congress cannot agree on anything and we are not looking at the future, we are just looking at today, we are not being as visionary as we should be, especially in the Senate, but we did pass America COMPETES.

And, I want to say that we were guided by Norm Augustine and his Committee, the "Rising Above the Gathering Storm" report that gave us a road map, and Congress, in a bipartisan way, started the progress on that road map. And, that is the way it ought to work, and I appreciate so much all you did to make that happen.

NASA, I think NASA was on the wrong path. Senator Nelson and I agreed on that. We were devaluing the future in favor of the present in this Administration, and with the help of the late Neil Armstrong, Gene Cernan, Jim Lovell—astronauts who stood up, and with the commitment of Congress, we were able to, I think, balance the plan that would keep a commercial opportunity alive for taxiing to the space station, but not at the expense of the next generation of space exploration which is beyond low earth orbit, and that was preserved. Again, Mr. Chairman, I really appreciate your willingness to work on that with us.

The FAA re-authorization bill, nobody talks about that being important, but it was huge. It gave our airports and the FAA the ability to plan enough that we could start building projects for runways, and safety, and efficiency, in our airports, and I am really pleased that we could do that, because it was those slots that were mentioned earlier that were the hold-up for 5 or 6 years, and we were able to pry that out.

The Spectrum Legislation that opened more airwaves for our wireless broadband network as well as providing our National First Responders more capability to have instant communications, unfortunately a lesson from 9/11 when everything got clogged, because we did not have enough wireless broadband capacity.

And, the Highway bill that included bus safety legislation—that was so important in taking a major step forward. Senator Brown and I worked on that, and we got that through the Committee, and we were able to put that in the Highway bill.

So, I think we have done some wonderful things, and I have loved being the Ranking Member of this Committee.

On this bill that we are going to hear about today, America COMPETES, I do give so much credit to Norm Augustine, and am so pleased that you could be with us today, because you did lead the effort with that fabulous Committee, to say we are behind on STEM education and here is how we think we ought to be going forward. And, our America COMPETES Act and the re-authorization of that Act certainly did put us in a better situation.

In the last decade, just to give you one example, growth in STEM jobs has been three times greater than non-STEM jobs. But today, only 30 percent of U.S. high school graduates are ready for college work in science, and 45 percent ready in math.

That is not going to produce the teachers that we need for the future, nor the scientists and engineers that we need for the future, to truly compete. Because of our commitment in COMPETES, the National Science Foundation has played a major role in STEM education, providing for $1 billion in educational scholarship programs, so that our professionals and people who majored in the STEM courses, science, hard science, engineering, math, would get their teacher certificates and teach our young people, because they are the ones who can inspire our young people to be able to see a future in STEM professions. And, it is with those enlightened teachers that we know we will have the scientists of the future come out.

We also authorized UTeach, which is a University of Texas program that allowed our majors in science, engineering and math to get teacher certificates through electives and, in their normal course time, be able to get teacher certification as well as major in these subjects, which has been a huge boon where it has been used, and I am hoping that in the re-authorization of America COMPETES we will be able to also fund the UTeach going nationwide.

And, I think that one good thing that was a step forward is that Congress spoke, and we did prioritize. Obviously we are in a budgetary crisis, and we all understand that, and I think we have to set a top line of spending, that should be 20 percent or 18 percent, in that range, of our gross domestic product. That has been the average through the years, but that is not the average right now. It is 26 percent. That is too high.

But, when we set that cap, we need to make sure we are funding priorities that are seedcorn for the future.

STEM courses, education, research, and NASA exploration are all areas, that are seedcorn for the future, and I hope that when I am gone, that you, Mr. Chairman, and this Committee, and all of the Members of the Congress will prioritize our spending, so that we are setting that cap at a low level, which we need to do, but prioritizing the future and the investment going forward. Thank you.

The CHAIRMAN. Thank you very much, and I will turn to Norman Augustine, retired Chairman and CEO of Lockheed Martin Corporation.

STATEMENT OF NORMAN R. AUGUSTINE, RETIRED CHAIRMAN AND CEO, LOCKHEED MARTIN CORPORATION

Mr. AUGUSTINE. Mr. Chairman, and members of the Committee, thank you very much for this opportunity to appear today. With your permission, I would like to note that I have had the great privilege of appearing as a witness before Senator Hutchinson many times over the years, and it truly has been a great privilege.

I should also note that I am not representing any organization today. I am here as a private citizen. Finally, with the Committee's permission, I would like to submit a statement for the record.

The CHAIRMAN. Of course.

Mr. AUGUSTINE. The America COMPETES Act, in my opinion, is of the utmost importance. It is about jobs, jobs for all Americans.

Jobs, of course, provide the basis for the quality of life that our citizens enjoy. Jobs provide the revenues that our government needs if it is to provide the services that our citizens have come to expect, everything from national security, to healthcare, to maintaining the infrastructure and more.

As has been noted, the America COMPETES Act began with a bipartisan request from both Houses, it was passed by overwhelming majorities of both Houses, and indeed it, I think, today represents one of the finest examples of bipartisanship, and bipartisanism is something we have not frequently had the opportunity to observe in recent years.

The National Academy study to which you have referred is of course known as the "Gathering Storm" study and report. We examined, at your request, America's competiveness outlook, and the bottom line was that the outlook was not very good. In fact, we were clearly losing ground to others.

The Academy has highlighted two areas deserving highest attention. The first of these concerns public K through 12 education, and the second, as you know, addressed basic research.

But, during the last few years, a new challenge has arisen. It is a challenge that, frankly, we never thought of when we did the work on the "Gathering Storm" report. It certainly, as far as I know, never occurred to any of the members, certainly not myself. It is that new challenge upon which I would like to focus my verbal remarks today.

What I refer to is the impact events of the last few years have had on America's great research universities. The "Gathering Storm" report cited our universities as one of the principal advantages that America has in competing globally along with our free enterprise system and our democracy. The *Times of London* has said that the top five universities in the entire world are all in America, as are 18 of the top 25.

Today, unfortunately, that position is in grave danger of being lost. The reversal of the economy and the decline in tax revenues, particularly at the state level, have resulted in our universities receiving the lowest fractions of the operating budgets from the state funds in over a quarter of a century.

The fact is that we have been privatizing our public universities. One consequence of this is that we have shifted the burden of education, higher education, to the students, and to the younger generation. This is threatening the American dream.

Over the past decade, tuition and fees have increased 85 percent on average across the country, and that is after financial aid has been included. In many states, such as California, the increases far exceed that amount.

This has not gone unnoticed in other nations—the challenges our universities are having. Fixing faculty salaries, even cutting salaries, laying off junior faculty, increasing teaching loads, and so on. In other countries they are trying to identify the most outstanding individuals in this country, such as the gentleman who sits next to me, to try to attract these people to their own universities.

Not long ago, I was in another country visiting a university that had just hired 14 new senior faculty members. Of those, 13 came from U.S. universities. But, as if that were not enough, there is more.

Most universities have barely changed in the past few hundred years. They largely consisted of a student, a professor, a book, a blackboard, and a piece of chalk. Today, the students carry the library around in their pocket, they do not need the blackboard and the chalk, and their professor may be thousands of miles away.

It is this wave of technological change that is engulfing our higher education system, and providing not only great challenges but also great opportunities—if we can manage it correctly.

Stanford University recently, as an example, put three courses on the web. They had 350,000 students sign up for those courses within a few days. Those students came from 190 different countries. The courses offered no degrees, but they also charged no tuition.

What can our government do with regard to a higher education? I think there are many things. I will cite just a few. Many are contentious, even within the higher education community.

Certainly one is to substantially increase support for basic research. Another is to be sure that government grants fully fund the research that they call for. Another is to refrain from using earmarks in awarding research contracts and grants. Another is to provide more need-based financial aid to students who are being excluded from educational opportunities.

I am aware, of course, as you pointed out, that our nation faces a very severe budget problem. However, my business background has taught me that, even in times of great duress when you have to cut overall budgets, and indeed I think we face such a situation in this country, we increase the budgets in some very critical areas, particularly those with long-term implications.

The distinguishing feature, I believe, is whether appropriations are for consumption or whether they are for investment. And, it is my belief that higher education, secondary education, and basic research, are indeed investments that will pay large returns for our country's citizens.

With that, I would encourage you to renew the America COMPETES Act, because it addresses exactly those issues that will have such a large impact on our country in the decades ahead.

Thank you, very much.

[The prepared statement of Mr. Augustine follows:]

PREPARED STATEMENT OF NORMAN R. AUGUSTINE, DENVER, COLORARO: RETIRED CHAIRMAN AND CEO, LOCKHEED MARTIN CORPORATION

Mr. Chairman and members of the Committee, thank you for inviting me to appear before you today and in particular to do so in the presence of such a distinguished group of colleagues.

I should begin by noting that I am not here representing any of the organizations with which I have been associated, but rather appear simply as a private citizen. I have chosen to devote a considerable part of my retirement to what I consider to be among the very most important issues affecting the future of America: namely, its competitiveness. This is a topic that has enjoyed strong bipartisan support—support that has made it possible to implement some of the recommendations that have been offered by organizations such as the Council on Competitiveness and the National Academies of Science, Engineering and Medicine in their document commonly referred to as the "Gathering Storm" report.

The quality of life of America's citizens is to a considerable degree founded upon their opportunity to find and hold quality jobs. Further, it is those jobs, and the firms that provide them, that generate the tax revenues which enable our government to provide the services upon which our citizens so heavily depend, including national security, protection against terrorists, healthcare, a modern physical infrastructure, and much more.

In fact, it is about jobs that I would like to speak today. Underlying any such discussion is the truly remarkable change that has taken place in the employment market in the past few decades and now seems to be accelerating. This change, in my judgment, has been brought about largely by two developments in science and technology. The first of these is the highly expanded use of modern commercial jet aircraft that make it possible to move things, including people, around the world at nearly the speed of sound. The second is the revolution in information systems that has made it possible to move knowledge . . . ideas, data, text . . . around the world literally at the speed of light.

A problem with a computer in New York can now be resolved by contacting an expert in Bangalore. A CAT-scan recorded in Chicago can be read by a radiologist in Sydney or Mumbai—while you wait. A surgeon in New York can remove the gall bladder of a patient in Paris using a remotely controlled robot. A video made in California can contribute to riots halfway around the world.

It is a world in which distance no longer matters. Americans no longer simply compete for jobs with their neighbors around the block, but rather with their neighbors around the globe. If one needs a car, it can readily be obtained from Japan, Germany or Korea. If one needs software, it can be written in India and sent, in a few milliseconds, back to the U.S. If one needs flowers, they can be delivered overnight from Holland.

The critical question, of course, is how well we as a nation are adapting to this new reality. That is in fact the question that was asked approximately seven years ago of the National Academies on a bipartisan basis by members of this body and the House of Representatives. The essence of the Academies' assessment as contained in the Gathering Storm report is that "Without a renewed effort to bolster the foundations of our competitiveness, we can expect to lose our privileged position. For the first time in generations, the Nation's children could face poorer prospects than their parents and grandparents did. We owe our current prosperity, security, and good health to the investments of past generations . . ."

Intel's Howard High's comments in this regard are fairly representative: "We go where the smart people are. Now our business operations are two-thirds in the U.S. and one-third overseas. But that ratio will flip over in the next ten years." Or, in the words of DuPont's then-CEO, Chad Holliday, "If the U.S. doesn't get its act together, DuPont is going to go to the countries that do." Bill Gates has said, "We are all going where the high I.Q.'s are."

The Academies' report offered 20 explicit, actionable recommendations to reverse the current decline in competitiveness, the top two which, in priority order, were to repair the U.S. K–12 public education system and to significantly increase the Nation's investment in basic research. The reason for this emphasis, as viewed by the members preparing the report, is that the K–12 system is currently the weakest link in producing the Human Capital needed for Americans to compete for jobs in a global economy, and investment in basic research is the enabler that leads to the Knowledge Capital that underlies a substantial portion of job creation. Worthy of note, the U.S. has long enjoyed a significant advantage in the availability of Financial Capital with which to underwrite innovation; however, Financial Capital today travels at the speed of light, without regard to political borders, as it seeks opportunities.

In one of the Gathering Storm reports the National Academies itemized factors that it considered to play a major role as corporations determine where to establish new research laboratories, engineering facilities, factories and logistics centers. Although the factors were by no means of equal importance, in ten of the twelve factors the U.S. was ranked as inferior to representative rapidly developing nations. The categories included, for example, the cost of labor . . . an area where Americans are accustomed to receiving wages that exceed global averages by *factors* of as much as ten or even more for assembly workers and five to ten for scientists and engineers.

Given these considerations, many researchers who have studied the revolution in competitiveness have concluded that the United States' competitive advantage will have to reside in superior innovation: that is, creating new knowledge through leading-edge research; transforming that knowledge into goods and services through world-class engineering; and being first to the marketplace with those goods and services through extraordinary entrepreneurialism.

With regard to Human Capital, in the most respected international test U.S. students now rank in 14th place in reading, 17th in science and 25th in mathematics. Needless to say, this is not a formula for success in the jobs race. Yet, the U.S. spends more per public school student than all but two other nations. The issue is not *what* we spend, but *how* we spend it. The most important two actions we could take to improve the situation are to bring the Free Enterprise System to K–12 education and to assure that every classroom has a teacher who possesses a core degree in the subject being taught. Teaching our children should be the most respected profession in America.

Turning to the subject of creating knowledge, significant growth in basic research funding followed the initial passage of the America COMPETES Act; however, investment in this endeavor has once again waned, particularly when inflation is included. Federal funding of basic research at universities and university research centers declined by 5.6 percent during the past year.

Margaret Thatcher described the importance of basic research in the following terms:

> ". . . although basic science can have colossal economic rewards, they are totally unpredictable . . . the value of Faraday's work today must be higher than the capitalization of all shares on the stock exchange. . . . The greatest economic benefits of scientific research have always resulted from advances in fundamental knowledge rather than the search for specific applications . . . transistors were not discovered by the entertainment industry . . . but by people working on wave mechanics and solid state physics. [Nuclear energy] was not discovered by oil companies with large budgets seeking alternative forms of energy, but by scientists like Einstein and Rutherford . . ."

Today, the iPhone, internet, GPS, solar power, nuclear power and far more owe their very existence to the work conducted over many years by scientists pursuing such fields as solid-state physics and quantum mechanics. It is likely that none of these scientists were thinking about such devices when they performed their work . . . but this is the nature of basic research.

Although I emphasize the importance of science and technology in these remarks, I would hasten to add that the single most important academic subject we can teach our children is how to read, since that is the basis of almost all learning. But it is also important to provide our youth, including our scientists and engineers, with a sound understanding of history, literature and ethics so that they can use their talents for the good of humankind.

Nonetheless, a number of studies have found that between 50 percent and 85 percent of the growth in America's GDP in recent decades can be attributed to advancements in science and engineering. Similarly, it has been shown that about two-thirds of the growth in U.S. productivity can be attributed to advancements in these same two disciplines. The challenge is not, *per se,* to increase jobs for scientists and engineers; only four percent of the U.S. workforce is composed of scientists and engineers. Even doubling that number would not have an overly profound impact on the U.S. employment outlook. The point is that that four percent disproportionately generates jobs for the other 96 percent of our citizenry.

A recent study reported in the Journal of International Commerce and Economics states that (in 2006) the 700 engineers working on Apple's iPod were accompanied by 14,000 other workers in the U.S. . . . and nearly 25,000 abroad. Floyd Kvamme, a highly regarded entrepreneur, has said that "Venture capital *is* the search for good engineers." Steve Jobs told the president of the United States that the reason Apple employs 700,000 workers overseas is because it can't find 30,000 engineers in the U.S. Data presented in the Chronicle of Higher Education reveal that during the past 30 years, an era of burgeoning importance of science and technology, the percentage growth in engineers ranks 27th among the 31 fields of study listed.

Perhaps the great irony is that America is never again likely to suffer a shortage of engineers. America's corporations have found a solution to that challenge which satisfies their shareholders. Simply stated, "If engineers are not available in America, simply move the engineering work abroad where there is in fact a rapidly growing body of qualified individuals." Similarly, in a world where distance does not matter, research can be moved abroad, and so can prototyping, manufacturing and logistics. In fact, an additional reason for doing so is to be near to one's customers and it has been estimated that by the mid 2020s there will be twice as many middle-income consumers in China as there are inhabitants in America. It has further been estimated that within a decade 80 percent of the world's middle class will reside in what are now categorized as developing nations.

It is occasionally argued that America is producing too many scientists. That, of course, is true. If one sufficiently under-invests in research then one will indeed have too many scientists. "If one does not purchase gasoline, there will be no need for cars."

Today, only about 15 percent of U.S. youth who *actually graduate* from high school (and nearly one-third do not) have the credentials to even *begin* a college curriculum in engineering. Of those who do begin, about 60 percent do not finish their studies in the that field. Additionally, the unfortunate fact is that U.S. youth show a surprising disinterest, even disdain, with respect to the study of science and engineering, notwithstanding their fascination with video games, television, automobiles and most other products of science and engineering.

A recent study by the National Science Foundation notes that in terms of the fraction of baccalaureate degrees that are granted in the field of engineering, the U.S. now ranks 79th among the 93 nations included in the study. The nation most closely resembling the U.S. in this regard in both engineering and science is Mozambique. The only countries that rank behind the U.S. are Bangladesh, Brunei, Burundi, Cambodia, Cameroon, Cuba, Gambia, Guyana, Lesotho, Luxembourg, Madagascar, Namibia, Saudi Arabia and Swaziland.

In the past America has been able to excel in science and engineering in considerable part because of its ability to attract outstanding foreign-born individuals to our universities and encourage them to remain and contribute to the creation of domestic jobs. In fact, about two-thirds of those receiving doctorates in engineering from U.S. universities have been foreign-born. However, this circumstance is beginning to change as opportunities for scientists and engineers expand abroad. Foreign graduate students now indicate much more frequently an intent to return to their native countries upon receiving their degrees and gaining a few years experience in the U.S. Our nation's policies regarding such matters as the granting of H1–B visas are exacerbating this problem.

Some individuals, particularly strong believers in the free-market system, simply say, "Let the free-market solve the problem." But the problem is that the free-market *is* solving the problem . . . it is just not doing so in a fashion that most Americans will like.

So what should we do? The answer is straightforward: we as a nation must *compete*. And that, of course, is what the America COMPETES Act is all about. Renewing the COMPETES Act is of the utmost importance. I cannot over-emphasize that fact. But as a mathematician might say, it is a necessary but not sufficient condition. We must also follow-through. In that regard, a very good beginning took place under the administrations of both President Bush and President Obama. Upon initial passage of the America COMPETES Act, investment in basic research increased, as did scholarships for future STEM teachers. ARPA–E was established, albeit under-funded. However, with the decline of the economy much of that progress has now waned. Meanwhile, U.S. corporations continue to spend over twice as much on litigation as on basic research; the pressures of the stock market cause U.S. firms to discount future investments such that research funding is greatly diminished; firms remain burdened with high medical costs and what recently became the highest stated corporate tax rate in the world.

When the Gathering Storm study was first published, as its chairman I was often asked to speak to government gatherings in other countries, ranging from Australia to Saudi Arabia to Singapore to Canada. Not only were these nations listening, many took action. Today, America's continuing decline in competitiveness is due not only to our own lack of aggressive action but to the fact that others are accelerating their competitiveness strategies.

When the Committee preparing the Gathering Storm report issued its second assessment five years after the first report, it concluded that America had fallen even further behind during the intervening period, noting, for example, that another six million students had dropped out of U.S. high schools during that period, placing themselves in positions of little opportunity to obtain quality jobs or to contribute to the creation of jobs for others.

But as if these challenges were not sufficient, an altogether new problem has arisen since the Gathering Storm report was prepared. This new challenge deals with an issue that, to the best of my knowledge, was unforeseen by any of our committee's members—most assuredly not by myself.

We had noted in our report that our Nation's great research universities were among America's most significant assets in the crusade to create jobs—along with our freedom and our free enterprise system. It is noteworthy that it is our universities that produce the talent we need to compete as well as much of the knowledge. Even today, according to *The Times of London,* the top five universities in the entire world and 18 of the top 25 are located in the United States.

But these same institutions are now endangered. The share of their operating expenses funded by state governments is rapidly declining and now represent the lowest fraction of such resources in a quarter of a century. In three decades state financial support of higher education as a fraction of personal income has, on average, declined by 71 percent. One result is, for example, that at the highly regarded public universities in California, tuition and fees have grown by 240 percent in the past dozen years. Throughout the Nation tuition and fees at public universities have increased by an average of 85 percent over the past decade, *net of financial aid.*

Faculty have on average seen their salaries decline by 1.2 percent during the past year—not including the effect of inflation; layoffs are not uncommon among junior faculty; and teaching loads are increasing. This reduction in state support is, in effect, privatizing our public universities—with much of the cost being shifted to the students—thereby fundamentally threatening the continuation of the American Dream. On the other hand, it may be appropriate for our universities to reconsider their own priorities and even their *raison d'être.* According to *USA Today,* major college football coaches receive an average compensation of $1.47 million per year, "a jump of nearly 55 percent in six seasons."

Such developments have led institutions of higher education in many other nations to prepare lists of exceptional faculty members in the U.S. whom they might attract to their countries. One foreign university that I recently visited had added 14 new senior faculty . . . of whom 13 came from America. The attractiveness of such offers is facilitated, in the case of engineering, by the fact that 40 percent of U.S. faculty members were born abroad.

But there is still more. A tsunami of an altogether different kind is now beginning to engulf America's universities. For some two centuries higher education around the globe has largely consisted of a professor, a library, a blackboard and a piece of chalk . . . seemingly managing to resist change with a truly remarkable tenacity. But now, when distance no longer matters, students carry entire libraries in their pockets and have access to extraordinary professors located throughout the world. Not long ago three courses at Stanford were offered online and 350,000 students from 190 countries promptly signed up. Although no degrees were offered, no tuition was sought.

It seems foregone that America's universities are going to have to remake themselves, and how well they are able to do so will have either a profound positive or negative impact on America's overall competitiveness. As this occurs, it will be of the utmost importance for government at all levels to recognize this challenge and, among other things, provide adequate funding of basic research; appropriately fund operating budgets; pay the true cost of research grants; increase need-based financial aid; and enable private universities to continue to build their endowments.

Several years ago while I was testifying before a committee of the Congress in support of increased funding for education and research a member asked whether I understood that America was suffering a budget crisis. I responded that I of course was aware of that circumstance, but that as an aeronautical engineer, during my career I had worked on a number of airplanes that during their development programs were too heavy to fly. Never once did we solve the problem by removing an engine. In the case of creating jobs for Americans, it is research, education and entrepreneurialism that *are* the engines that propel the creation of jobs.

Over the years, my experience in business has taught me that even during difficult times when budgets are being cut, and I indeed saw such times when, for example, during about a five-year period some 40 percent of the employees in our industry and three-fourths of the companies departed, some areas must be provided additional funds. The point is that one must continue to invest in the future, even during hard times. The key is to distinguish between spending for consumption and spending for investment.

Again, thank you for the privilege of sharing these views with you.

NORMAN R. AUGUSTINE was raised in Colorado and attended Princeton University where he graduated with a BSE in Aeronautical Engineering, magna cum laude, and an MSE. He was elected to Phi Beta Kappa, Tau Beta Pi and Sigma Xi.

In 1958 he joined the Douglas Aircraft Company in California where he worked as a Research Engineer, Program Manager and Chief Engineer. Beginning in 1965, he served in the Office of the Secretary of Defense as Assistant Director of Defense Research and Engineering. He joined LTV Missiles and Space Company in 1970, serving as Vice President, Advanced Programs and Marketing. In 1973 he returned to the Government as Assistant Secretary of the Army and in 1975 became Under Secretary of the Army, and later Acting Secretary of the Army. Joining Martin Marietta Corporation in 1977 as Vice President of Technical Operations, he was elected as CEO in 1987 and chairman in 1988, having previously been President and COO. He served as President of Lockheed Martin Corporation upon the formation of that company in 1995, and became CEO later that year. He retired as Chairman and CEO of Lockheed Martin in August 1997, at which time he became a Lecturer with the Rank of Professor on the faculty of Princeton University where he served until July 1999.

Mr. Augustine was Chairman and Principal Officer of the American Red Cross for nine years, Chairman of the Council of the National Academy of Engineering, President and Chairman of the Association of the United States Army, Chairman of the Aerospace Industries Association, and Chairman of the Defense Science Board. He is a former President of the American Institute of Aeronautics and Astronautics and the Boy Scouts of America. He is a former member of the Board of Directors of ConocoPhillips, Black & Decker, Proctor & Gamble and Lockheed Martin, and was a member of the Board of Trustees of Colonial Williamsburg. He is a Regent of the University System of Maryland, Trustee Emeritus of Johns Hopkins and a former member of the Board of Trustees of Princeton and MIT. He is a member of the Advisory Board of the Department of Homeland Security and the Department of Energy, was a member of the Hart/Rudman Commission on National Security, and served for 16 years on the President's Council of Advisors on Science and Technology. He is a member of the American Philosophical Society, the National Academy of Sciences and the Council on Foreign Relations, and is a Fellow of the National Academy of Arts and Sciences and the Explorers Club.

Mr. Augustine has been presented the National Medal of Technology by the President of the United States and received the Joint Chiefs of Staff Distinguished Public Service Award. He has five times received the Department of Defense's highest civilian decoration, the Distinguished Service Medal. He is co-author of *The Defense Revolution* and *Shakespeare In Charge* and author of *Augustine's Laws* and *Augustine's Travels.* He holds 29 honorary degrees and was selected by Who's Who in America and the Library of Congress as one of "Fifty Great Americans" on the occasion of Who's Who's fiftieth anniversary. He has traveled in 111 countries and stood on both the North and South Poles of the earth.

The CHAIRMAN. Thank you, sir, very much.

And now, I would call upon Mr. Wieman.

STATEMENT OF CARL E. WIEMAN, FORMER ASSOCIATE DIRECTOR, SCIENCE DIVISION, OFFICE OF SCIENCE AND TECHNOLOGY POLICY

Dr. WIEMAN. Summarizing the state of STEM education, there has really been very little change in either the level of interest in STEM or the mastery of STEM subjects by American students over the past few decades.

Here I would like to offer a new perspective on STEM education. It both explains this lack of progress and indicates what must be done to achieve improvement. This perspective is based on advances in research on learning, what I have come to appreciate after studying research across several different fields for a dozen years or so and doing some research on this myself.

What has been shown is that the learning of complex expertise, such as the mastery of math and science, is not a matter of transferring knowledge into sufficiently talented brains, which is the traditional model of learning. Rather, such learning of expertise is a development of the brain, the actual change in its structure, in response to strenuous practice of the components of thinking that make up expertise. This is rather similar to where a muscle grows and strengthens in response to strenuous use. Innate talent really plays very little role in this learning process.

Now, this research-based perspective on learning implies that effective STEM teaching is similar to effective coaching. A good athletic coach, first, figures out the essential skills that make up mastery in their sport. Then they create challenging practice activities that quite explicitly practice these necessary skills. Third, the coach motivates their charges to work very hard at this practice. And fourth, they offer frequent and targeted constructive feedback to guide improvement. All of these same ideas apply to teaching STEM, with the STEM thinking skills replacing the list of athletic skills.

These STEM expert teaching skills are discussed in more detail in my written testimony.

This effective research-based teaching has been demonstrated, but is profoundly different from what is found in the typical K–12 or college classroom. Also, the skills needed to teach in this fashion are not part of the normal training that is provided to STEM teachers.

Now, if these were changed, the U.S. would go from being a laggard to the world leader in STEM education. And, if the quality of teaching and teacher training are not improved, nothing else will make much difference in our STEM education outcomes.

However, to improve teaching, one must change some of the basic institutional incentives that serve to maintain the status quo, and most Federal STEM education programs, rather than drive improvements, are actually serving to preserve these incentive systems and prop up this dismissal status quo.

In the case of K–12 teaching, the institutional incentives are for teacher training programs primarily to maximize their revenue by admitting and graduating as many students as possible. One result of this is that the STEM admissions standards and curriculum requirements for teacher training programs are very low, often the lowest of any college major.

Much of the Federal STEM teacher training dollars go in the form of easily available scholarships, and the result is there are more students of questionable quality with money to pay to attend such programs of questionable quality. Thus, these funds are actually preserving, rather than improving, the status quo.

At the college level, teaching methods have been demonstrated, based on the ideas presented above, that are far superior to the prevailing lecture method, typically achieving twice the learning and half the failure and dropout rates, at the same cost.

Now, if these methods were widely implemented, it would dramatically increase the number and quality of STEM graduates, and it would greatly improve the content mastery and models of teaching provided to future K–12 teachers. This is a necessary first step to fixing K–12 STEM teaching.

However, these superior teaching methods are not being adopted at the university level, largely because the Federal Government is paying universities and their faculty members $30 billion a year to focus their attention on research productivity. That money has resulted in an incentive system at universities that has been very effective at maximizing research output, but it has had the unintended consequence that adoption of best teaching practices and improvements in student educational outcomes has a very low priority.

Now, it is not going to be easy to improve STEM teaching in the way I have described. You will need to overturn established practices and incentive systems that are supported by powerful vested interests. However, we have already spent plenty of money on fads and easy fixes that do not work, and advances in research on learning at least now provide a much clearer picture than was available in the past for what is necessary to truly make a difference.

Thank you for the opportunity to make these comments.

[The prepared statement of Dr. Wieman follows:]

PREPARED STATEMENT OF CARL E. WIEMAN, FORMER ASSOCIATE DIRECTOR, SCIENCE DIVISION, OFFICE OF SCIENCE AND TECHNOLOGY POLICY

Applying New Research to Improve Science Education

Insights from several fields on how people learn to become experts can help us to dramatically enhance the effectiveness of science, technology, engineering, and mathematics education.

Science, technology, engineering, and mathematics (STEM) education is critical to the U.S. future because of its relevance to the economy and the need for a citizenry able to make wise decisions on issues faced by modern society. Calls for improvement have become increasingly widespread and desperate, and there have been countless national, local, and private programs aimed at improving STEM education, but there continues to be little discernible change in either student achievement or student interest in STEM. Articles and letters in the spring and summer 2012 editions of Issues extensively discussed STEM education issues. Largely absent from these discussions, however, is attention to learning.

This is unfortunate because there is an extensive body of recent research on how learning is accomplished, with clear implications for what constitutes effective STEM teaching and how that differs from typical current teaching at the K12 and college levels. Failure to understand this learning-

focused perspective is also a root cause of the failures of many reform efforts. Furthermore, the incentive systems in higher education, in part driven by government programs, act to prevent the adoption of these research-based ideas in teaching and teacher training.

A new approach

The current approach to STEM education is built on the assumption that students come to school with different brains and that education is the process of immersing these brains in knowledge, facts, and procedures, which those brains then absorb to varying degrees. The extent of absorption is largely determined by the inherent talent and interest of the brain. Thus, those with STEM "talent" will succeed, usually easily, whereas the others have no hope. Research advances in cognitive psychology, brain physiology, and classroom practices are painting a very different picture of how learning works.

We are learning that complex expertise is a matter not of filling up an existing brain with knowledge, but of brain development. This development comes about as the result of intensive practice of the cognitive processes that define the specific expertise, and effective teaching can greatly reduce the impact of initial differences among the learners.

This research has established important underlying causes and principles and important specific results, but it is far from complete. More research is needed on how to accomplish the desired learning most effectively over the full range of STEM skills and potential learners in our classrooms, as well as how to best train teachers.

What is learning STEM?

The appropriate STEM educational goal should be to maximize the extent to which the learners develop expertise in the relevant subject, where expertise is defined by what scientists and engineers do. This is not to say that every learner should become a scientist or engineer, or that they could become one by taking any one class, but rather that the value of the educational experiences should be measured by their effectiveness at changing the thinking of the learner to be more like that of an expert when solving problems and making decisions relevant to the discipline. As discussed in the National Research Council study *Taking Science to School,* modern research has shown that children have the capability to begin this process and learn complex reasoning at much earlier ages than previously thought, at least from the beginning of their formal schooling. Naturally, it is necessary and desirable for younger children to learn less specialized expertise encompassing a broader range of disciplines than would be the case for older learners.

Expertise has been extensively studied across a variety of disciplines. Experts in any given discipline have large amounts of knowledge and particular discipline-specific ways in which they organize and apply that knowledge. Experts also have the capability to monitor their own thinking when solving problems in their discipline, testing their understanding and the suitability of different solution approaches, and making corrections as appropriate. There are a number of more specific components of expertise that apply across the STEM disciplines. These include the use of:

- Discipline-and topic-specific mental models involving relevant cause and effect relationships that are used to make predictions about behavior and solve problems.
- Sophisticated criteria for deciding which of these models do or don't apply in a given situation, and processes for regularly testing the appropriateness of the model being used.
- Complex pattern-recognition systems for distinguishing between relevant and irrelevant information.
- Specialized representations.
- Criteria for selecting the likely optimum solution method to a given problem.
- Self-checking and sense making, including the use of discipline-specific criteria for checking the suitability of a solution method and a result.
- Procedures and knowledge, some discipline-specific and some not, that have become so automatic with practice that they can be used without requiring conscious mental processing. This frees up cognitive resources for other tasks.

Many of these components involve making decisions in the presence of limited information—a vital but often educationally neglected aspect of expertise. All of these components are embedded in the knowledge and practices of the discipline, but that knowledge is linked with the process and context, which are essential elements for knowledge to be useful. Similarly, measuring the learning of most elements of this expertise is inherently discipline-specific.

How is learning achieved?

Researchers are also making great progress in determining how expertise is acquired, with the basic conclusion being that those cognitive processes that are explicitly and strenuously practiced are those that are learned. The learning of complex expertise is thus quite analogous to muscle development. In response to the extended strenuous use of a muscle, it grows and strengthens. In a similar way, the brain changes and develops in response to its strenuous extended use. Advances in brain science have now made it possible to observe some of these changes.

Specific elements, collectively called "deliberate practice," have been identified as key to acquiring expertise across many different areas of human endeavor. This involves the learner solving a set of tasks or problems that are challenging but doable and that involve explicitly practicing the appropriate expert thinking and performance. The tasks must be sufficiently difficult to require intense effort by the learner if progress is to be made, and hence must be adjusted to the current state of expertise of the learner. Deliberate practice also includes internal reflection by the learner and feedback from the teacher/coach, during which the achievement of the learner is compared with a standard, and there is an analysis of how to make further progress. The level of expert-like performance has been shown to be closely linked to the duration of deliberate practice. Thousands of hours of deliberate practice are typically required to reach an elite level of performance.

This research has a number of important implications for STEM education. First, it means that learning is inherently difficult, so that motivation plays a large role.

To succeed, the learner must be convinced of the value of the goal and believe that hard work, not innate talent, is critical. Second, activities that do not demand substantial focus and effort provide little educational value. Listening passively to a lecture, doing many easy, repetitive tasks, or practicing irrelevant skills produce little learning. Third, although there are distinct differences among learners, for the great majority the amount of time spent in deliberate practice transcends any other variables in determining learning outcomes.

Implications for teaching

From the learning perspective, effective teaching is that which maximizes the learner's engagement in cognitive processes that are necessary to develop expertise. As such, the characteristics of an effective teacher are very analogous to those of a good athletic coach: designing effective practice activities that break down and collectively embody all the essential component skills, motivating the learner to work hard on them, and providing effective feedback.

The effective STEM teacher must:

- Understand expert thinking and design suitable practice tasks.
- Target student thinking and learning needs. Such tasks must be appropriate to the level of the learner and be effective at building on learners' current thinking to move them to higher expertise. The teacher must be aware of and connect with the prior thinking of the learner as well as have an understanding of the cognitive difficulties posed by the material.
- Motivate the student to put in the extensive effort that is required for learning. This involves generating a sense of self-efficacy and ownership of the learning; making the subject interesting, relevant, and inspiring; developing a sense of identity in the learner as a STEM expert; and other factors that affect motivation. How to do this in practice is dependent on the subject matter and the characteristics of the learner—their prior experience, level of mastery, and individual and sociocultural values.
- Provide effective feedback that is timely and directly addresses the student's thinking. This requires the teacher to recognize the student's thought processes, be aware of the typical cognitive challenges with the material, and prepare particular questions, tasks, and examples to help the learner overcome those challenges. Research has shown several effective means of providing feedback, including short, focused lectures if the student has been carefully prepared to learn from that lecture.
- Understand how learning works, and use that to guide all of their activities. In addition to the research on learning expertise, this includes other well-established principles regarding how the human brain processes and remembers information that are relevant to education, such as the limitations of the brain's short-term memory and what processes enhance long-term retention.

Although many of these instructional activities are easier to do one on one, there are a variety of pedagogical techniques and simple technologies that extend the capabilities of the teacher to provide these elements of instruction to many students at once in a classroom, often by productively using student-student interactions. Examples of approaches that have demonstrated their effectiveness can be found in recommended reading articles by Michelle Smith and by Louis Deslauriers *et al.*

Effective STEM teaching is a specific learned expertise that includes, and goes well beyond, STEM subject expertise. Developing such teaching expertise should be the focus of STEM teacher training. Teachers must have a deep mastery of the content so they know what expert thinking is, but they also must have "pedagogical content knowledge." This is an understanding of how students learn the particular content and the challenges and opportunities for facilitation of learning at a topic-specific level.

This view of STEM teaching as optimizing the development of expertise provides clearer and more detailed guidance than what is currently available from the classroom research on effective teaching. Most of the classroom research on effective teaching looks at K–12 classrooms and attempts to link student progress on standardized tests with various teacher credentials, traits, or training. Although there has been progress, it is limited because of the challenges of carrying out educational research of this type. There are a large number of uncontrolled variables in the K–12 school environment that affect student learning, the standardized tests are often of questionable validity for measuring learning, teacher credentials and training are at best tenuous measures of their content mastery and pedagogical content mastery, and the general level of these masteries is low in the K–12 teacher population. The level of mastery is particularly low in elementary-and middle-school teachers. All of these factors conspire to make the signals small and easily masked by other variables.

At the college level, the number of uncontrolled variables is much smaller, and as reviewed in the NRC report *Discipline-Based Education Research,* it is much clearer that those teachers who practice pedagogy that supports deliberate practice by the students show substantially greater learning gains than are achieved with traditional lectures. For example, the learning of concepts for all students is improved, with typical increases of 50 to 100 percent, and the dropout and failure rates are roughly halved.

Shortcomings of the current system

Typical K–16 STEM teaching contrasts starkly with what I have just described as effective teaching. At the K–12 level, although there are notable exceptions, the typical teacher starts out with a very weak idea of what it means to think like a scientist or engineer. Very few K–12 teachers, including many who were STEM majors, acquire sufficient domain expertise in their preparation. Hence, the typical teacher begins with very little capability to properly design the requisite learning tasks. Furthermore, their lack of content mastery, combined with a lack of pedagogical content knowledge, prevents them from properly evaluating and guiding the students' thinking. Much of the time, students in class are listening passively or practicing procedures that neither have the desired cognitive elements nor require the level of strenuousness that are important for learning.

Teachers at both the K–12 and undergraduate levels also have limited knowledge of the learning process and what is known about how the mind functions, resulting in common educational practices that are clearly counter to what research shows is optimum, both for processing and learning information in the classroom environment and for achieving long-term retention. Another shortcoming of teaching at all levels is the strong tendency to teach "anti-creativity.' Students are taught and tested on solving well-defined artificial problems posed by the teacher, where the goal is to use the specific procedure the teacher intended to produce the intended answer. This requires essentially the opposite cognitive process from STEM creativity, which is primarily recognizing the relevance of previously unappreciated relationships or information to solve a problem in a novel way.

At the undergraduate level, STEM teachers generally have a high degree of subject expertise. Unfortunately, this is not reflected in the cognitive activities of the students in the classroom, which again consist largely of listening, with very little cognitive processing needed or possible. Students do homework and exam problems that primarily involve practicing solution procedures, albeit complex and/or mathematically sophisticated ones. However, the assigned problems almost never explicitly require the sorts of cognitive tasks that are the critical components of expertise described above. Instructors also often suffer from "expert blindness,' failing to recognize and make explicit many mental processes that they have practiced so much that they are automatic.

Another problem at the postsecondary level is the common belief that effective teaching is only a matter of providing information to the learner, with everything else being the responsibility of the learners and/or their innate limitations. It is common to assume that motivation, and even curiosity about a subject, are entirely the responsibility of the student, even when the student does not yet know much about the subject.

Failure of reform efforts

The perspective on learning that I have described also explains the failure of many STEM reform efforts.

Belief in the importance of innate talent or other characteristics. Schools have long focused educational resources on learners that have been identified in some manner as exceptional. Although the research shows that all brains learn expertise in fundamentally the same way, that is not to say that all learners are the same. Many different aspects affect the learning of a particular student. Previous learning experiences and sociocultural background and values obviously play a role. There is a large and contentious literature as to the relative significance of innate ability/talent or the optimum learning style of each individual, with many claims and fads supported by little or questionable research.

Researchers have tried for decades to demonstrate that success is largely determined by some innate traits and that by measuring those traits with IQ tests or other means, one can preselect children who are destined for greatness and then focus educational resources on them. This field of research has been plagued by difficulties with selection bias and the lack of adequate controls. Although there continues to be some debate, the bulk of the research is now showing that, excepting the lower tail of the distribution consisting of students with pathologies, the predictive value of any such early tests of intellectual capability is very limited. From an educational policy point of view, the most important research result is that any predictive value is small compared to the later effects of the amount and quality of deliberate practice undertaken by the learner. That predictive value is also small compared to the effects of the learners' and teachers' beliefs about learning and the learners' intellectual capabilities. Although early measurements of talent, or IQ, independent of other factors have at best small correlation with later accomplishment, simply labeling someone as talented or not has a much larger correlation. It should be noted that in many schools students who are classified as deficient by tests with very weak predictive value are put into classrooms that provide much less deliberate practice than the norm, whereas the opposite is true for students who are classified as gifted. The subsequent difference in learning outcomes for the two groups provides an apparent validation for what is merely a self-fulfilling prophecy. Given these findings, human capital is clearly maximized by assuming that, except for students with obvious pathologies, every student is capable of great achievement in STEM and should be provided with the educational experiences that will maximize their learning.

The idea that for each individual there is a unique learning style is surprisingly widespread given the lack of supporting evidence for this claim, and in fact significant evidence showing the contrary, as reviewed by Hal Pashler of the University of California at San Diego and others.

Because of the presence of many different factors that influence a student's success in STEM, including the mind's natural tendency to learn, some students do succeed in spite of the many deficiencies in the educational system. Most notably, parents can play a major role in both early cognitive development and STEM interest, which are major contributors to later success. However, optimizing the teaching as I described would allow success for a much larger fraction of the population, as well as allowing those students who are successful in the current system to do even better.

Poor standards and accountability. Standards have had a major role in education reform efforts, but they are very much a double-edged sword. Although good definitions and assessments of the desired learning are essential, bad definitions are very harmful. There are tremendous pitfalls in developing good, widely used standards and assessments. The old concept of learning, combined with expert blindness and individual biases, exerts a constant pressure on standards to devolve into a list of facts covering everyone's areas of interest, with little connection to the essential elements of expertise. The shortcomings in the standards are then reinforced by the large-scale assessment systems, because measuring a student's knowledge of memorized facts and simple procedures is much cheaper and easier than authentic measurements of expertise. So although good standards and good assessment must be at the core of any serious STEM education improvement effort, poor standards and poor assessments can have very negative consequences. The recent National Academy of Sciences–led effort on new science standards, starting with a carefully thought-out guiding framework, is an excellent start, but this must avoid all the pitfalls as it is carried through to large-scale assessments of student mastery. Finally, good standards and assessments will never by themselves result in substantial improvement in STEM education, because they are only one of several essential components to achieving learning.

Competitions and other informal science programs: Attempting to separate the inspiration from the learning. Motivation in its entirety, including the elements of inspiration, is such fundamental requirement for learning that any approach that separates it from any aspect the learning process is doomed to be ineffective. Unfortunately, a large number of government and private programs that support the many science and engineering competitions and out-of-school programs assume that they are separable. The assumption of such programs is that by inspiring children through competitions or other enrichment experiences, they will then thrive in formal school experiences that provide little motivation or inspiration and still go on to achieve STEM success. Given the questionable assumptions about the learning process that underlie these programs, we should not be surprised that there is little evidence that such programs ultimately succeed, and some limited evidence to the contrary. The past 20 years have seen an explosion in the number of participants in engineering-oriented competitions such as First Robotics and others, while the fraction of the population getting college degrees in engineering has remained constant. A study by Rena Subotnik and colleagues that tracked high-school Westinghouse (now Intel) talent search winners, an extraordinarily elite group already deeply immersed in science, found that a substantial fraction, including nearly half of the women, had switched out of science within a few years, largely because of their experiences in the formal education system. It is not that such enrichment experiences are bad, just that they are inherently limited in their effectiveness. Programs that introduce these motivational elements as an integral part of every aspect of the STEM learning process, particularly in formal schooling, would probably be more effective.

Silver-bullet solutions. A number of prominent scientists, beginning as far back as the Sputnik era, have introduced new curricula based on their understanding of the subject. The implicit assumption of such efforts is that someone with a high level of subject expertise can simply explain to novices how an expert thinks about the subject, and the novices (either students or K–12 teachers) will then embrace and use that way of thinking and be experts themselves. This assumption is strongly contradicted by the research on expertise and learning, and so the failure of such efforts is no surprise.

A number of elements such as school organization, teacher salaries, working conditions, and others have been put forth as the element that, if changed, will fix STEM education. Although some of these may well be a piece of a comprehensive reform, they are not particularly STEM-specific and by themselves will do little to address the basic shortcomings in STEM teaching and learning.

The conceptual flaws of STEM teacher in-service professional development. The Federal government spends a few hundred million dollars each year on in-service teacher professional development in STEM, with states and private sources providing additional funding. Suzanne Wilson's review of the effectiveness of such professional development activities finds evidence of little success and identifies structural factors that inhibit effectiveness. From the perspective of learning expertise, it is clear why teacher professional development is fundamentally ineffective and expensive. If these teachers failed to master the STEM content as full-time students in high school and college, it is unrealistic to think they will now achieve that mastery as employees through some intermittent, part-time, usually voluntary activity on top of their primary job.

Why change is hard

First, nearly everyone who has gone to school perceives himself or herself to be an expert on education, resulting in a tendency to seize on solutions that overlook the complexities of the education system and how the brain learns. Second, there are long-neglected structural elements and incentives within the higher education system that actively inhibit the adoption of better teaching methods and the better training of teachers. These deserve special attention.

Improving undergraduate STEM teaching to produce better-educated graduates and better-trained future K–12 teachers is a necessary first step in any serious effort to improve STEM education, but there are several barriers to accomplishing this. First, the tens of billions of dollars of federal research funding going to academic institutions, combined with no accountability for educational outcomes at the levels of the department or the individual faculty member, have shaped the university incentive system to focus almost entirely on research. Thus, STEM departments and individual faculty members, regardless of their personal inclinations, are forced to prioritize their time accordingly, with the adoption of better teaching practices, improved student outcomes, and contributing to the training of future K–12 STEM teachers ranking very low. Second, to the limited extent that there are data, STEM instructional practices appear to be similarly poor across the range of post-secondary institutions. This is probably because the research-intensive universities produce most of the Ph.D.s, who become the faculty at all types of institutions, and so the educational values and standards of the research-intensive universities have become pervasive. Third, with a few exceptions, the individual academic departments retain nearly absolute control over what they teach and how they teach. Deans, provosts, and especially presidents have almost no authority over, or even knowledge of, educational practices in use by the faculty. Any successful effort to change undergraduate STEM teaching must change the incentives and accountability at the level of the academic department and the individual faculty member in the research-intensive universities.

A possible option would be to make a department's eligibility to receive Federal STEM research funds contingent on the reporting and publication of undergraduate teaching practices and student outcomes. A standard reporting format would make it possible to compare the extent to which departments and institutions employ best practices. Prospective students could then make more-informed decisions about which institution and department would provide them with the best education.

Most K–12 teacher preparation programs have a local focus, and they make money for the institutions of which they are a part. There is no accepted professional standard for teacher training, and there is a financial incentive for institutions to accept and graduate as many education majors as possible. This has resulted in low standards, particularly in math and science, with teacher education programs frequently having the lowest math and science requirements of any major at the institution. This also means that they attract students with the greatest antipathy toward math and science. Research by my colleagues has found that elementary education majors have far more novice-like attitudes about physics than do students in any other major at the university. Federal programs to support the training of K–12 STEM teachers provide easily available scholarship money, which reinforces the status quo by ensuring a plentiful supply of students in spite of the programs' low quality. Rewarding institutions that produce graduates with the expertise needed to be highly effective teachers is an essential step in bringing about the massive change that is needed in the preparation of STEM teachers.

Focusing on STEM learning and how it is achieved provides a valuable perspective for understanding the shortcomings of the educational system and how it can be improved. It clarifies why the current system is producing poor results and explains why current and past efforts to improve the situation have had little effect. However, it also offers hope. Improvement is contingent on changes in the incentive system in higher education to bring about the widespread adoption of STEM teaching methods and the training of K–12 teachers that embody what research has shown is important for effective learning. These tasks are admittedly challenging, but the results would be dramatic. The United States would go from being a laggard in STEM education to the world leader.

Recommended reading

S. Ambrose, M. Bridges, M. DiPietro, M. Lovett, and M. Norman, *How Learning Works: Seven Research-Based Principles for Smart Teaching* (San Francisco, CA: J. Wiley and Sons, 2010).

J. Bransford, A. Brown, and R. Cocking, eds., *How People Learn; Brain, Mind, Experience, and School* (expanded edition) (Washington, DC: National Academies Press, 2000).

G. Colvin, *Talent Is Overrated: What Really Separates World-Class Performers from Everybody Else* (New York: Penguin Books, 2008).

L. Deslauriers, E. Schelew, and C. Wieman; "Improved Learning in a Large-Enrollment Physics Class," *Science* 332, no. 6031 (2011): 862–864; and particularly the supporting online material.

R. Duschl, H. Schweingruber, and A. Shouse, eds., *Taking Science to School; Learning and Teaching Science in Grades K–8* (Washington, DC: National Academies Press, 2007).

C. Dweck, *Self-Theories: Their Role in Motivation, Personality, and Development* (Philadelphia, PS: Taylor and Francis, 2000).

K. A. Ericsson, N. Charness, P. Feltovich, and R. Hoffman, eds., *The Cambridge Handbook of Expertise and Expert Performance* (Cambridge: Cambridge Univ. Press, 2006),

H. Pashler, M. McDaniel, D. Rohrer, and R. Bjork, "Learning Styles: Concepts and Evidence," *Psychological Science in the Public Interest* 9 (2009): 105.

S. Singer, N. Nielsen, and H. Schweingruber, eds., *Understanding and Improving Learning in Undergraduate Science and Engineering* (Washington, DC: National Academies Press, 2012).

M. Smith, "A Fishy Way to Discuss Multiple Genes Affecting the Same Trait," *PLoS Biology* 10, no 3 (2012): e1001279. doi:10.1371/journal.pbio.1001279.

Carl Wieman (*gilbertwieman@gmail.com*), professor of physics and director of science education initiatives at the University of Colorado and the University of British Columbia, served as the associate director for science in the White House Office of Science and Technology Policy from Sept 2010 to June 2012. He received the Nobel Prize in Physics in 2001.

The CHAIRMAN. Thank you, sir.

You are all being too succinct.

Dr. Jeffrey Furman.

STATEMENT OF JEFFREY L. FURMAN, PH.D., ASSOCIATE PROFESSOR OF STRATEGY AND INNOVATION, BOSTON UNIVERSITY; AND RESEARCH ASSOCIATE, NATIONAL BUREAU OF ECONOMIC RESEARCH

Dr. FURMAN. Good afternoon, Chairman, Ranking Member, members of the Committee. It is an honor for me to be here today. This is the first time that I have testified before Congress. I am Jeff Furman, Associate Professor of Strategy and Innovation at Boston University and Research Associate at the National Bureau of Economic Research.

I have understood my invitation today as relating to two issues about which I have some expertise. First, I believe I have been asked to talk a little about the overall drivers of country-level scientific and innovative output, and the role of the Federal Government in supporting science and innovation. Second, I understand that I was invited to talk a little bit about the 5-year history of the America COMPETES legislation. I am one of a number of economists studying innovation who has worked in a modest amount of detail on these issues, although I suspect that members of the Committee are more knowledgeable about the COMPETES legislation than academics who study innovation.

With regard to the first substantive issue, country-level science and innovation, the first question I would like to address is what is the argument for Federal investment in science and technology?

It is a relatively standard question that was addressed famously by Vannevar Bush in a letter to President Roosevelt at the close of World War II. Bush's argument was that science and innovation, particularly early stage innovation, are public goods, and that much like national defense, firms do not have the incentives to provide these types of investments because firms will be unable to capture the complete set of returns associated with those investments. As a consequence, there is a very strong argument for governments stepping in to help the private sector in supporting science and early stage innovation, as these would otherwise not receive the socially optimal level of investments.

The idea that the private sector will underinvest in innovation is somewhat like free trade, an idea on which economists are in general agreement. There are some differences in points of view, but the idea that science and early stage innovation as a public good is something on which most economists agree.

That said, there is a different question which relates to whether science and innovation leadership is essential. An alternative is, rather than having the United States be the world leader in science and innovation, we could ask other countries to make those leading investments and then simply imitate what they have done. The evidence does not suggest that this is a particularly ideal strategy for leading in jobs or leading in industries, although many countries have been following this approach with some degree of success. Indeed, a follower approach to science and innovation is often taken by countries aiming to get closer to the global frontier.

There is not as much empirical evidence in large-scale studies as an economist would ideally like to have on these topics, but there are both a great deal of casual evidence that scientific and innovation leadership provides benefits, as well as many of the ideas that other panelists and Committee members have cited today.

In work led by Scott Stern of MIT and Michael Porter of Harvard and me, we have looked at what drives country-level outcomes in innovation. One note is that our approach implicitly addressed whether culture was a driver of national leadership in science and innovation.

Our results are inconsistent with this hypothesis, as most of the exciting developments in country-level innovation over the past 25 years come from countries whose cultures have been relatively consistent over the past 100, 200, or even 300 years. Indeed, the areas in which countries seem to have made improvements that lead to outcomes is that they figure out ways to continuously ratchet up their investments in innovation, both at the Federal level and then also at the private level.

There is, unfortunately, no obvious magic bullet, other than having consistent upgrading in science capabilities. This is a little bit like the race of the red queen.

There is also a great deal of evidence that, at the regional level, leadership has its benefits. Some of this evidence is casual. We can look to Boston and San Francisco as two areas with great scientific institutions that lead both in science and then also in associated innovation. But, there is increasing evidence in economics, including work by Naomi Housman, who looks at the positive impact of the Bayh-Dole Act on industries and local universities that have been positively affected by the Bayh-Dole Act.

So, it appears as if investments in science and innovation have a substantial impact on the local regions and countries in which they are made. This suggests, to me at least, that leadership in these areas going forward is, indeed, as many of the folks in this room surmised, soundly based in evidence.

The second issue to which I should turn is an assessment of the COMPETES legislation. To be precise, I do not think an assessment is a very strong way to describe what economists have been able to do so far in this particular area.

Typically economists are very good at direct assessments of very specific individual programs. That is not possible with the COMPETES legislation because there are so many programs that are a part of it, and because it is very difficult to assess the impact of authorization relative to specific funding through appropriations.

I think the summary of what economists can say about the COMPETES Act, is that there are some very clear and notable achievements that arise directly from the legislation. These include the creation of ARPA–E, changes in and expansion of the National Institute of Standards and Technology, the ability for data to become centralized to evaluate teaching outcomes, which I believe John may be able to say a good deal about, the creation of Federal prize authority and the expansion of the Federal prize authority. One other achievement of the COMPETES legislation is that it to have galvanized momentum within Federal agencies to continuously emphasize science and innovation outcomes.

That said, a full assessment of the COMPETES Act requires a nuanced view of what we think might have occurred in the absence of the Acts. If we compare relative to the hope of the “Gathering

Storm" report, it appears that as if much has been unrealized. Indeed, many of the programs, as the Chairman has pointed out, have not been funded. But, as has also been pointed out, a great deal has been achieved, simply by unifying a bipartisan consensus around the idea that science and innovation investments should receive Federal attention. And, it is very difficult to assess what may have happened in physical science research and engineering research in the absence of the COMPETES legislation.

I think I would like to close on that note. It is difficult for an academic to keep things to five minutes, but I hope I have done so. Thank you.

[The prepared statement of Dr. Furman follows:]

PREPARED STATEMENT OF JEFFREY L. FURMAN, PH.D., ASSOCIATE PROFESSOR OF STRATEGY AND INNOVATION, BOSTON UNIVERSITY; AND RESEARCH ASSOCIATE, NATIONAL BUREAU OF ECONOMIC RESEARCH [1]

I. Introductory Remarks

Thank you very much for this invitation. It is an honor to testify before this Committee and I am grateful for the invitation. A common complaint about Washington is that there is gridlock in Congress. I, however, have the great pleasure of conducting research on Science and Innovation Policy, an issue for which there has been both wide-ranging, bi-partisan support for the majority of the past century and a tradition of national successes that demonstrate the contributions of the public sector, private sector, and interactions between the two.

I will begin with a brief introduction of my background and research. I am an Associate Professor of Strategy & Innovation at Boston University and a Research Associate at the National Bureau of Economic Research (NBER). I hold a Ph.D. from the Massachusetts Institute of Technology in Strategy & International Management. My official training is in management scholarship, although much of the work that I do is based in economics and contributes to research in that field.

My principal research interests have addressed three general questions:

(1) What are the historical drivers of national innovative output? Stated somewhat differently, this question asks, "Why are some countries more innovative than others and what have historically follower nations, like Israel and South Korea, done to close the gap in innovation between themselves and historical leader countries, like Germany, Japan, and the United States? [2]

(2) What is the role of location in the R&D productivity of science-based firms? For example, in this research line, I have investigated whether pharmaceutical companies' drug discovery efforts are, indeed, more productive when they are located in high-science areas, like Boston, Philadelphia, and San Diego.[3]

[1] These comments heavily draw upon text the paper, "The America COMPETES Acts: The Future of U.S. Physical Science & Engineering Research?" forthcoming, forthcoming in, Josh Lerner & Scott Stern, ed, *Innovation Policy and the Economy* Vol 13, Chicago, IL: University of Chicago Press. The discussion of the America COMPETES legislation in that paper draws heavily on reports written by the Congressional Research Service.

[2] See, *e.g.,* J.L. Furman (2011) "The Economics of Science and Technology Leadership," Leadership in Science and Technology: A Reference Handbook, William Sims Bainbridge, Editor, Sage Publications; J.L. Furman and R. Hayes (2004) "Catching up or standing still? National innovative productivity among 'follower' nations, 1978–1999," *Research Policy;* J.L. Furman, S. Stern, and M.E. Porter (2002), "The determinants of national innovative capacity," *Research Policy;* S. Stern, M.E. Porter, and J.L. Furman (2000) "Understanding the drivers of national innovative capacity—Implications for Central European economies," *Wirtschaftspolitische Blätter;* M.E. Porter, S. Stern, and J.L. Furman (2000) "Los Factores Impulsores de la Capacidad Innovadora Nacional: Implicaciones para España y America Latina" *Claves de la Economia Mundial.*

[3] See, *e.g.,* J.L. Furman and Megan MacGarvie (2009) "Organizational Innovation & Academic Collaboration: The role of universities in the emergence of U.S. Pharmaceutical research laboratories," *Industry & Corporate Change;* J.L. Furman & M. MacGarvie (2008) "When the pill peddlers met the scientists: The antecedents and implications of early collaborations between U.S. pharmaceutical firms and universities," Essays in Economic & Business History; J.L. Furman & M. MacGarvie (2007) "Academic science and early industrial research labs in the pharmaceutical industry," *Journal of Economic Behavior & Organization;* and J.L. Furman, M. Kyle,

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(3) How do particular institutions and public policies affect science and innovation output? For example, I have investigated (a) the impact of the U.S. human embryonic stem cell policy on national leadership in this research area; (b) the contribution of Biological Resource Centers, like the American Type Culture Collection in nearby Manassas, VA, to the rate of knowledge accumulation, and (c) the ability of the system of academic retractions to limit the negative impact of false publications. I should note that this last line of research has been supported by a grant from the National Science Foundation's Science of Science and Innovation Policy program and that it has been my most recent line of work.[4]

In each of these projects, I should recognize the contributions of my co-authors, most notably, Fiona Murray and Scott Stern of MIT's Sloan School and Megan MacGarvie, my colleague at Boston University.

My understanding of my invitation today is that my charge is to talk about two main issues: (a) the Federal role in Science and Innovation Policy and (b) America COMPETES Act. I address these issues in turn.

II. The Federal Role in Science & Innovation Policy

II.1. History & the general argument for Federal support for science & innovation

Although the aim of "promot[ing] the progress of science and useful arts" was articulated in the U.S. Constitution as a power of Congress, this power was expressly linked to providing incentives to authors and inventors.[5] Consistent with the specificity of these aims, the U.S. Federal Government administered the patent system but did not engage in much centralized policy-making regarding science and technology during its first century.[6] During and following the Civil War, the Federal government began to expand its role in promoting science and technology by developing some key institutions, including the development of research-oriented universities under the Morrill Acts of 1862 and 1890, the Hatch Act of 1887, the National Academy of Sciences (NAS). The second major wave of Federal science-and technology-related investments began during the first two decades of the 20th century and accelerated during World War I. This effort included the establishment of the National Bureau of Standards (1901), the Public Health Service (1912), and the National Advisory Committee for Aeronautics (1915), the Naval Consulting Board (1915), and the National Research Council (1916).

The argument for active government participation in funding and guiding basic scientific research was made famously by Vannevar Bush, Director of the Office of Scientific Research and Development under Franklin Delano Roosevelt during World War II, in his monograph, *Science: The Endless Frontier.*[7] Bush argued both that the scientific enterprise was a key to economic growth and improvements in social welfare.[8] His logic for suggesting Federal support for science funding was

I. Cockburn, & R. Henderson (2005) "Public & Private Spillovers, Location, and the Productivity of Pharmaceutical Research," *Annales d'Economie et de Statistique.*

[4] J.L. Furman, F. Murray, & S. Stern (2012) "Growing Stem Cells: The Impact of U.S. Policy on the Organization of Scientific Research," *Journal of Policy Analysis & Management;* J. Furman, K. Jensen, & F. Murray (2012) "Governing knowledge production in the scientific community: Quantifying the impact of retractions," *Research Policy;* J.L. Furman & S. Stern (2011) "Climbing atop the shoulders of giants: The impact of institutions on cumulative research," *American Economic Review;* J.L. Furman, F. Murray, & S. Stern (2010) "More for the research dollar," *Nature;* S. Stern & J.L. Furman (2004) "A penny for your quotes?: The impact of biological resource centers on life sciences research," in *Biological Resource Centers: Knowledge Hubs for the Life Sciences,* ed. S. Stern, Washington, D.C.: Brookings Institution Press.

[5] *U.S. Constitution,* Article I, Section 8, Clauses 1 & 8: "The Congress shall have Power . . . To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries." Clause 1 precedes the ellipsis; Clause 8 follows the ellipsis.

[6] The Federal Government did engage support some efforts related to science and technology, however. For example, Federal support for the exploration of Lewis and Clark yielded numerous contributions to scientific knowledge, including contributions to natural history (including discoveries of new plants and animals), meteorology, and cartography (Ambrose, Stephen E. (1996) *Undaunted Courage: Meriwether Lewis, Thomas Jefferson, and the Opening of the American West,* (1996) New York, NY: Simon & Schuster; Cutright, Paul Russell (1969) *Lewis & Clark: Pioneering Naturalists,* Urbana, IL: University of Illinois Press).

[7] Bush, Vannevar (1945) "Science The Endless Frontier," A Report to the President by Vannevar Bush, Director of the Office of Scientific Research and Development, Washington, D.C.: United States Government Printing Office.

[8] "Advances in science when put to practical use mean more jobs, higher wages, shorter hours, more abundant crops, more leisure for recreation, for study, for learning how to live without the deadening drudgery which has been the burden of the common man for ages past. Advances in science will also bring higher standards of living, will lead to the prevention or cure of dis-

straightforward and reflected an understanding of positive externalities: Since investments in basic scientific research invariably diffuse to other organizations in way that limits the ability of for-profit firms to capture sufficient returns from such investments, society overall faces higher incentives to invest in basic research than do for-profit firms. Thus, basic research can be usefully classified as a public good and, in the absence of government support, the private sector will provide an inefficiently low investment in science and risky innovation. Bush argued that government should step into the void and assume an active role in supporting scientific research. Bush's vision resulted in the creation of the National Science Foundation in 1950 and has constituted the rationale for government investment in basic science since that time.[9] The arguments have taken on an additional salience during the debates on national competitiveness that surfaced during the 1980s, when American economic preeminence in several industries, including automobiles and consumer electronics, faced challenges from imports from numerous countries, including Germany and Japan, and during the 2000s, in light of the substantial economic development of several countries that had been historically imitation oriented than innovation-driven, including South Korea, China, and India.

II.2. National leadership and the role of location

The argument that science and early-stage innovation are public goods requiring government support to achieve optimal levels is especially compelling in a world in which there is only one country or in which one country is the clear leader in science and technology, as the U.S. was during the years following World War II, or in which there is no trade between countries. In such a scenario, if the unchallenged leader country (or the global science investment body) were to curtail investments in science and technology or were to slow the rate at which it built on prior research advances, global technological improvements would stagnate, as would global economic growth.[10]

If a number of countries have relatively similar levels of scientific development, national decisions regarding scientific investment become more interrelated. This complicates matters, as one country's optimal investment decisions will depend on the investments of other nations and on the rapidity and completeness with which knowledge diffuses. If scientific and technical knowledge diffuses slowly and incompletely (or if it is particularly expensive for non-innovator countries to imitate leader countries, *i.e.,* if catch-up is slow), then a leader country is likely to obtain high returns to its investments in science. If, however, scientific and technical knowledge diffuses sufficiently swiftly and effectively, then there may not be a substantial benefit to being a leader country, as fast-follower countries can free ride on the investments of leaders.

Thus, unless it is the unchallenged global technological leader, it will only be valuable for a country to pursue a strategy of scientific and technical leadership in the presence of relatively strong increasing returns to science and technology investment and relatively local knowledge diffusion. Stated somewhat differently, in order for locally-generated knowledge to be translated into scientific and/or technical leadership, researchers in close proximity to an original discovery must be able to exploit that discovery more rapidly, intensively, and, ultimately, successfully, than researchers who are further away.[11]

Despite improvements in information technology that have lowered the communication costs and made it easier to spread information, the often-anticipated "death of distance" has failed to materialize. Indeed, proclamations that the world is flat (Friedman, 2005) overlook the importance of local knowledge spillovers, which are quite strong, even in science, one of the areas in which ideas are most likely to flow

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eases, will promote conservation of our limited national resources, and will assure means of defense against aggression" (Bush, 1945, p. 10).

[9] Building on Bush's ideas, economists beginning with Nelson (1959) and Arrow (1962) described as a public, non-rivalrous, non-excludable good which creates higher social welfare than private benefits. Considering the central role of scientific and technical knowledge play a central role in economic growth and social welfare (Solow, 1956; Abramovitz, 1956), the fact that scientific knowledge evidences the properties of a public good suggest that the creation and accretion of knowledge should be central goals for national policymakers.

[10] See Jones, Charles I. (1995) "R&D Based Models of Economic Growth," *Journal of Political Economy,* 103: 739–784.

[11] Furman, Jeffrey L. (2011) "The Economics of Science and Technology Leadership," *Leadership in Science and Technology: A Reference Handbook,* William Sims Bainbridge, Editor, Sage Publications, Chapter 3.

most effectively.[12] While transportation costs have declined for physical goods and cost of direct communication has also declined, empirical evidence suggests value of proximity has increased in most industries and most sectors as well. Research suggests that investments in science and technology at the world's frontier yield spillovers that are constrained to geographically proximate regions (Jaffe, Trajtenberg, & Henderson, 1993) and that even small barriers to diffusion can explain large differences in productivity levels among the most advanced nations (Eaton & Kortum, 1999).[13] Thus, there are at least some reasons to believe that investments in scientific and technical leadership may yield high rates of return than investments encouraging fast-follower approaches. Within the United States, those regions that have been historically knowledge-intensive have experienced greater economic success, even as the information economy has developed further (Glaeser and Ponzetto, 2010).[14] As well, there is also evidence that U.S. Federal science and innovation policies, including the Bayh-Dole Act have both a local and national impact on economic outcomes, such as patenting and job creation (Hausman, 2012; Saha & Weinberg, 2011).[15]

More broadly, research suggests that those countries and geographic regions that have invested most heavily in scientific and technological infrastructure and adopt innovation-oriented policies have substantially improved their science bases and innovative capacity (Furman and Hayes, 2004).[16] The evidence suggests, though, that while many leader countries have continued to make science and technology investments at increasing rates, a number of former follower countries have increased their commitments to innovation at even greater rates. This has contributed to the globalization of science and technology and has contributed to the erosion of the gap between the leader and emerging innovator countries. Concerns about American competitiveness in the wake of such advances by other countries were among the factors prompting the Gathering Storm Report, the Bush Administration's American Competitiveness Initiative, and the America COMPETES Act. I turn to the lattermost of these in my next comments.

III. The America COMPETES legislation

III.1. Introductory comments

My expertise with the America COMPETES legislation is of a particular kind: I prepared an overview of the legislation's history, components, and funding for a workshop of the National Bureau of Economic Research. The paper had two purposes: (1) to provide an overview of the COMPETES legislation for academic economists who were broadly aware of the legislation but not familiar with its particulars and (2) to lay the groundwork for future projects to assess its impact and effectiveness. I believe that I was relatively successful in the former task, thanks principally to my ability to build on the work of the Congressional Research Service, but the latter task is especially challenging. Economics has made extraordinary progress over the past couple of decades in "program evaluation," *i.e.,* evaluating specific public programs, such as job creation programs, and we are beginning to make progress in evaluating science and innovation policy as well. The field finds it much more difficult, however, to evaluate packages of programs and broad-based changes in funding, such as those associated with the COMPETES acts. Thus, I consider the research I have done on the COMPETES legislation as the beginning rather than the end of analysis on this subject and I believe that this is an area in which economists and policymakers can find useful ground for interaction.

III.2. Overview of analysis

The America COMPETES legislation, including the initial America COMPETES Act of 2007 (ACA 2007) and America COMPETES Reauthorization Act of 2010 (ACA

[12] Friedman, Thomas L. (2007) *The World is Flat: A Brief History of the Twenty-first Century.* New York, NY: Farrar, Straus and Giroux.

[13] Adam Jaffe, Manuel Trajtenberg, Rebecca M. Henderson (1993) "Geographic localization of knowledge spillovers as evidenced by patent citation," *Quarterly Journal of Economics,* 79(3): 577–598 and Eaton, Jonathan and Samuel Kortum, "Trade in ideas patenting and productivity in the OECD," *Journal of International Economics,* 40(3–4), 251–278.

[14] Edward L. Glaeser, Giacomo A. M. Ponzetto. (2010) "Did the Death of Distance Hurt Detroit and Help New York?" in Edward L. Glaeser, editor, *Agglomeration Economics,* Chicago, IL: University of Chicago Press.

[15] Naomi Hausman (2011) "University Innovation, Local Economic Growth, and Entrepreneurship," working paper; Saha, Subra B. and Bruce A. Weinberg (2011) "A Framework for Quantifying the Economic Spillovers from Government Activity Applied to Science," working paper.

[16] Furman, Jeffrey L. and Richard Hayes (2004) "Catching up or standing still: Catching up or standing still? National innovative productivity among 'follower' countries, 1978–1999," *Research* Policy, 33, 1329–1354.

2010), was one of the prominent bipartisan legislative achievements of the past decade and was seen as having the potential to be the most notable science and innovation policy initiative of the new millennium.[17] To date, however, limited systematic analysis of the America COMPETES Acts has been undertaken.[18] My analysis of the Act has left me with two central impressions:

(1) *The achievements of the legislation can be reasonably viewed as substantial from the perspective of analyzing what may have happened in the absence of the legislation.* Key achievements that were enabled by the Acts include important expansions to the power of Federal agencies to implement innovation prize programs, the creation of Advanced Research Projects Agency—Energy (ARPA–E), funding for the National Institutes of Standards and Technology (NIST), substantial funding for programs at the National Science Foundation (NSF), the harder-to-measure-enabling of agencies to implement programs consistent with the spirit of the COMPETES Acts, and, perhaps most importantly, the maintenance of a tenuous but consistent bipartisan consensus to preserve the funding of physical science and engineering programs even in the face of budgetary difficulties of historical proportions. It is reasonable to conclude that, absent the authorization of funding for science and engineering programs called for by the COMPETES Acts, the level of commitment to these areas would have waned over the past half-decade that U.S. leadership in science and innovation would have suffered as a consequence.

(2) *Relative to the standards established by the COMPETES legislation itself, much of the promise of the Acts is yet to be realized.* Perhaps the most salient observation about the ACA to the external observer is that a substantial fraction of the funds authorized by the 2007 and 2010 Acts was not appropriated by Congress and that many of the specified programs have either not materialized or have been created but at funding levels much lower than their initial authorizations. This appears to be particularly the case for STEM education funding. Table 1 of my testimony reproduces a table from a 2009 Congressional Research Service report identifying programs authorized for funding under the 2007 Act that did and did not receive appropriations between the 2007 Act and 2009.

In my understanding, the COMPETES legislation embraced a broad-ranging series of goals. I will highlight six of these goals and give my impressions of the extent to which progress has been made on these issues. The issues include:

(a) *the "Doubling Path," i.e.,* the aim of doubling the funding for Federal investment in the physical sciences and engineering

(b) *ARPA–E,* the establishment and implementation of the Advanced Research Project Agency—Energy, built on the DARPA model

(c) *Improvements in America's STEM education infrastructure*

(d) *Modification of programs at the National Institute of Standards and Technology (NIST)*

(e) *Expansion of Federal Prize authority,* which was a specific initiative of the 2010 Reauthorization Act that was not included in the 2007 Act

(f) *Modifications to other Federal programs and clarification of Federal science and innovation responsibilities*

I address each of these issues in greater detail below.

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[17] See, for example, Broder, David (2007) "Thankless Bipartisanship," *Washington Post,* May 3, 2007, A18; Ensign, John (2007) "Why the America Competes Act is Vital," *Innovation,* 5(3); National Governor's Association (2007) "NGA Praises Congressional Passage of the America COMPETES Act," press release, August 6, 2007, *http://www.nga.org/cms/home/news-room/news-releases/page__2007/col2-content/main-content-list/title__nga-praises-congressional-passage-of-the-america-competes-act.html* accessed 15 June 2012; ASTRA (2007) "Congress Passes, President Signs America COMPETES Act," *Alliance for Science & Technology Research In America: ASTRA Briefs,* 6(6), 10–14; and American Physical Society (2008) "Supporters of America COMPETES Bill Praise Its Passage, Urge Federal Funding," *American Physical Society—Capital Hill Quarterly,* 3(1), 1.

[18] The notable exception to this is the extensive work by the Congressional Research Service, including the efforts of Deborah Stine and Heather B. Gonzalez, who have written regular updates on COMPETES Act policy issues and funding, and John F. Sargent, who has tracked budgeting for COMPETES Act programs relative to historical trends. Their work is cited throughout this paper and it forms the basis of much of the chapter's analysis.

III.3. The Doubling Path

One of the most prominent features of the COMPETES legislation was the "Doubling Path," the aim of doubling of Federal investment in the physical sciences and engineering between relative to the 2006 baseline. The 2007 Act aimed to achieve this result by 2013, while the 2010 Act re-targeted for 2015. Figures 1 & 2 attached below reflect the extent of funding under the COMPETES Act. Both are based in large measure on the efforts of the Congressional Research Service. Figure 1 documents that realized levels of funding and the extent of funding appropriated and authorized for the future have been systematically revised downwards from the initial aims of the *Gathering Storm Report,* the American Competitiveness Initiative, and the 2007 and 2010 Acts. Indeed, the current rate of funding increase for physical sciences and engineering is not appreciably greater than it was prior to the COMPETES legislation.

Whether one views this as a success or not depends substantially on the perspective that one takes: Federal investment in physical science and engineering has not kept pace with the specifications of either COMPETES Act; however, in contrast to many areas of the Federal budget, funding for these areas has not declined. Thus, investment in these areas is relative to other budget priorities is greater than it was prior to the COMPETES legislation and is likely substantially greater than it would have been in the absence of the 2007 and 2010 appropriations.

III.4. ARPA–E

The Advanced Research Projects Agency-Energy (ARPA–E) at the Department of Energy was articulated by both COMPETES Acts, the *Gathering Storm Report,* and the American Competitiveness Initiative. The agency was created in the 2007, received $15 million in the FY 2009 budget, but did not receive substantial funding until the 2009 ARRA appropriated $400 million, which enabled ARPA–E to begin to solicit research proposals and fund research projects. ARPA–E's did not receive appropriations in FY 2010, although it did receive nearly $180 million in FY 2011 and an estimated $275 million in FY 2012. These funding levels have enabled ARPA–E to award $521.7 million in grants to approximately 180 awardees as of March 2012. The agency issued a call for $150 million in additional proposals in March 2012.[19] In addition to its research funding, the Agency has held three Energy Innovation Summits that showcase research by ARPA–E awardees, applicants, and other contributors. Although the overall level of funding for ARPA–E has not reached the levels envisioned by *The Gathering Storm* and is substantially lower than the DARPA annual budget ($3.2 billion), ARPA–E can be considered as an important outcome associated with the COMPETES Acts, particularly in light of the fact that the total estimated annual U.S. investment in energy-related R&D is approximately $5.1 billion.[20] It is currently too early to assess the impact of ARPA–E on energy innovation; however, studies like those conducted by Erica Fuchs of the nature of DARPA research[21] and could be insightful and could set the stage for further evaluations of ARPA–E's performance.

III.5 STEM Education

The aim of expanding and improving U.S. STEM education was another of the signature initiatives of the 2007 and 2010 Acts. The legislation embraced three particular aims: (a) increasing the number of STEM teachers, particularly those of high quality and with exceptional training, and improving the depth of existing teachers' in STEM areas; (b) exposing a larger number of U.S. students to STEM education and attracting more into post-secondary STEM education and STEM-linked careers; and (c) improving investments in STEM education among women and historically under-represented minorities, and high-need schools. In this regard, the evidence is mixed. Some programs specified by the COMPETES legislation did receive funding, although few received funding at the levels authorized by either Act. For example, the Teachers for a Competitive Tomorrow: Baccalaureate Degrees and Master's Degrees programs, which were authorized by both COMPETES Acts, received annual average funding of approximately $1 million, although each had been authorized to receive more than $100 million in each fiscal year. Many programs, including the

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[19] ARPA–E (2012) "ARPA–E issues open call for transformational energy technologies," March 2, 2012, *http://arpa-e.energy.gov/media/news/tabid/83/vw/1/itemid/49/Default.aspx;* accessed March 2012.

[20] President's Council of Advisors on Science and Technology (2010) "Report to the President on accelerating the pace of change in energy technologies through an integrated Federal energy policy," November 10, 2010; *http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-energy-tech-report.pdf;* accessed January 2012.

[21] Erica R.H. Fuchs (2010) "Rethinking the role of the state in technology development: DARPA and the case for embedded network governance," *Research Policy,* 39(9), 1133–1147.

Department of Energy's Experiential-Based Learning Opportunities; Early Career Awards for Science, Engineering, and Mathematics Researchers; Discovery Science and Engineering Innovation Institutes; Protecting America's Competitive Edge (PACE) Graduate Fellowship Program; and Distinguished Scientist Program, each of which was authorized for between $10 million and $30 million in funding in FY2010, did not receive appropriations.

My understanding is that the NSF, which is the agency with the greatest responsibility for STEM education, has been able to support some STEM initiatives, even as the STEM education programs authorized by the COMPETES Acts have been winnowed and real (rather than nominal) for education and training programs have declined from 2003 to 2011. In particular, it appears as if the NSF has able to support postsecondary student funding, through the Graduate Research Fellowship (GRF) and Integrative Graduate Education and Research Traineeship (IGERT) programs by increasing the fraction of funding derived from its Research & Related Activities account.[22]

Overall, however, it does not appear as if the COMPETES legislation has substantially shifted investment in STEM education along the dimensions of its three initially articulated goals. Again, however, it does not appear as if STEM education, or associated outcomes, have declined substantially during the COMPETES era and this, itself, may constitute a substantial victory.

III.5. Modification of NIST programs

The modification of programs at the National Institute for Standards and Technology (NIST) was another clearly articulated goal of the COMPETES Act. While I was not able to conduct a rate-of-return analysis on the changes, it appears as if substantial progress has been made in funding and programs consistent with this aim. The Advanced Technology Program was replaced with the Technology Innovation Program, which was ultimately eliminated; the Hollings Manufacturing Extension Partnership Programs have been extended; and funding for both NIST Core Research and Facilities has been realized at levels not inconsistent with those envisioned by the COMPETES legislation. It is noteworthy that the levels of funding for NIST funding are orders of magnitude below those of other agencies, including the Department of Energy and the NSF.

III.6. Prizes

The 2010 COMPETES Reauthorization Act greatly enhanced the ability of Federal agencies to reward progress in science and innovation with prizes. Agencies may conduct prize contests of up to $50 million with existing appropriations. The approval of prize authority has led to the establishment of a clearinghouse for Federal prize programs, *www.challenge.gov,* which posts prize descriptions, eligibility conditions, submissions procedures, timelines, and rules. As of March 2012, *www.challenge.gov* hosted more than 150 prize challenges, representing more than forty Federal agencies.[23] One of the most ambitious Federal prize efforts was an initiative sponsored by the Department of Health and Human Services. Called the "Investing in Innovation" (i2) initiative, the effort involved a novel $5 million effort aimed at initiating innovations in Health Information Technology. A number of Federal prize programs, most notably those operated by NASA, have already become the subject of academic study.[24]

The extent of Federal prize programs continues to grow and it is too soon to measure the overall impact of such programs on innovation. The current scope of prize funding is many orders of magnitude smaller than Federal intramural research programs; however, it is possible that success with Federal prizes may contribute to momentum for yet larger attempts at inducements, such as those described by Kremer and colleagues.[25] More broadly, the opportunity for Federal agencies to conduct innovation challenges affords greater latitude for organizational innovation than existed in the past. It is possible that the seeds sown by expanded Federal prize authority will redound in ways that exceed the specific dollar value of prizes

[22] Gonzalez, Heather B. (2012) "An Analysis of STEM Education Funding at the NSF: Trends and Policy Discussion," *Congressional Research Service reports,* 9 April 2012.

[23] Office of Science and Technology Policy (2012) "Implementation of Federal Prize Authority: Progress Report," Executive Office of the President, March 2012.

[24] See, in particular, the work of Karim Lakhani and colleagues, including Kevin J. Boudreau, Nicola Lacetera, & Karim Lakhani (2011) "Incentives and Problem Uncertainty in Innovation Contests: An Empirical Analysis," *Management Science,* 57(5), 843–863.

[25] Michael Kremer and Heidi Williams (2010) "Incentivizing innovation: Adding to the toolkit," in Josh Lerner and Scott Stern, eds., *Innovation Policy and the Economy,* Volume 10, University of Chicago Press, 1–17.

offered by Federal agencies; at the moment, however, it is too soon to evaluate either this possibility or the specific impact of Federal prize authority on innovation.

III.7. Additional aims

In addition to the objectives I address above, the COMPETES legislation also addressed additional aims, including the support of high-risk, high-rewards projects within each executive agency; and greater coordination of Federal science and technology investments. I speak to progress on some of these dimensions in my working paper on the Act, but regret a lack of time to discuss these in greater detail during testimony today.

IV. Concluding Remarks

I would like to address three areas in my concluding remarks. First, I would like to provide a quick summary of my attempt to understand the impact of the COMPETES legislation. My impression is the COMPETES Acts have led to a number of truly significant achievements. These include the development of ARPA–E, which seems like it is off to an effective start, the enhancement of Federal prize authority, the energizing of Federal agencies around S&E objectives, and, perhaps most importantly in the long-term, the reaffirmation and codification of bipartisan support for physical science and engineering investment. The Acts also appear to have resulted in a substantial positive impact on Federal investments in S&E relative to what might have occurred in the absence of these Acts. That said, it is important to recognize that the level of S&E funding has not kept pace with the authorizations of either Act and that a number of the objectives of the Acts, most notably those related to STEM education, have been omitted from appropriations throughout the half-decade since the initial Act.

A second issue that I would love to address is the question, "What is the optimal level of funding for S&E?" While the consensus in economics is that the rate of return to additional Federal investment is still high, unfortunately, it does not appear to me that there is a consensus in economics about the number or fraction of GDP that identifies the optimal level of investment. There is consensus that leadership in science and innovation continues to reap rewards in terms of jobs, productivity, and living standards, even as the world becomes increasingly connected and information flows ever faster across borders. In the spirit of the glass-half-full, I can say that science and innovation policy studies are developing more rapidly than in the past and, although labor studies and other areas of economics have a longer history of policy evaluation, this area of economics is making strides and we should be able to provide more guidance to policy in the future than we have in the past.

The final issue I would like to address regards ideas for what may be done in an era of limited budgets to improve S&E competitiveness. From the standpoint of my profession, this is a bit reckless as I do not link each suggestion directly to a specific study; however, I believe that the ideas have a solid basis in prior research. One issue around which there is consensus in economics is that leadership in the human capital race is important for overall science and engineering leadership. Supporting the ability of universities to attract the world's best, brightest, and most motivated students and then enabling those individuals to remain in the United States, to continue their contributions to science and innovation, and to encourage those individuals to develop growing businesses is an idea around which there is substantial consensus among economists who study innovation. Two other ideas for which there is general support are the initiatives to support industry commercialization of university-generated ideas, potentially through subsidies or tax credits, and continued advocacy of intellectual property abroad. Two additional ideas that I will risk are that it would be helpful for Congressional acts and Federal initiatives to be formulated with an eye towards enabling program evaluation and rate of return calculations and the idea that development of scientific and innovation capabilities abroad does raise all sails, both by contributing to the increasingly rapid pace of technological development and by improving the capabilities of American universities and firms via competition. Science and innovation are not a zero-sum game. Improvements in scientific and innovative capabilities abroad augur well for American consumers and for American firms seeking less-expensive, more valuable intermediate goods. However, the evidence does suggest that the greatest rewards in terms of jobs, productivity advantages, and social welfare (or lifestyle) do accrue to those geographic regions with leadership in scientific and technical capabilities.

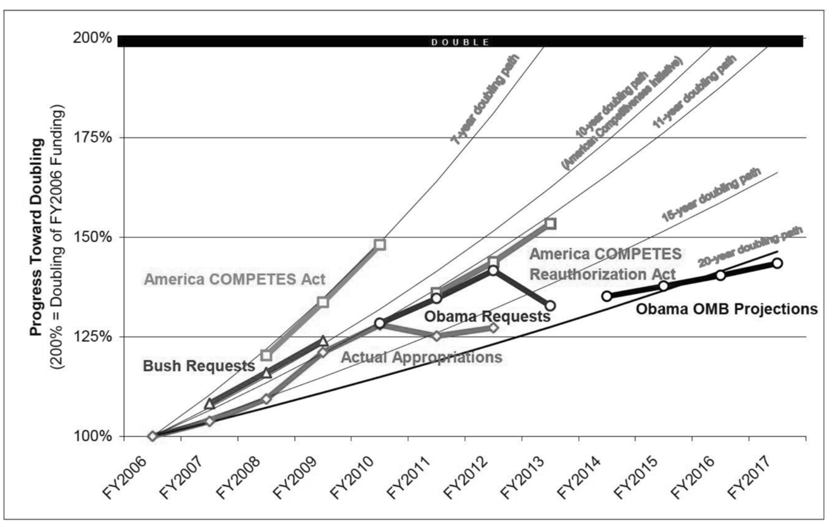
Table 1—Overview of FY 2009 Funding Authorizations for 2007 America COMPETES Act Programs

Funding includes both FY 2009 Omnibus Appropriations Act and American Recovery and Reinvestment Act	
Programs Presumably Not Funded in FY 2009	Programs Funded at Authorized Levels in FY 2009
Department of Energy • Pilot Program of Grants to Specialty Schools for Science and Mathematics • Experiential Based Learning Opportunities • Summer Institutes • National Energy Education Development • Nuclear Science Talent Expansion Program • Hydrocarbon Systems Science Talent Expansion Program • Early Career Awards for Science, Engineering, and Mathematics Researchers • Discovery Science and Engineering Innovation Institutes • Protecting America's Competitive Edge Graduate Fellowship Program • Distinguished Scientist Program *Department of Education* • Advanced Placement & International Baccalaureate Program • Math Now • Summer Term Education Program • Math Skills for Secondary Skill Students • Advancing America Through Foreign Language Partnership Program • Mathematics and Science Partnership Bonus Grants *National Science Foundation* • Laboratory Science Pilot Program	*Department of Energy* • Office of Science *National Science Foundation* • Research & Related Activities • Major Research Instrumentation • Professional Science Master's Degree Program • Robert Noyce Teacher Scholarship Program • Graduate Research Fellowship Program • Major Research Equipment and Facilities Construction *NIST* • Scientific & Technical Research and Services • Construction & Maintenance

Source: Deborah D. Stine (2009) "America COMPETES Act: Programs, Funding, and Selected Issues," Congressional Research Service, RL3428, April 17, 2009.

Figure 1. The "Doubling Path" in Research Funding for the Physical Sciences

Figure tracks potential doubling of Federal funding for science and technology, including funding for the NSF, DOE Office of Science, and NIST Core Research and Construction relative to FY 2006 appropriations levels.



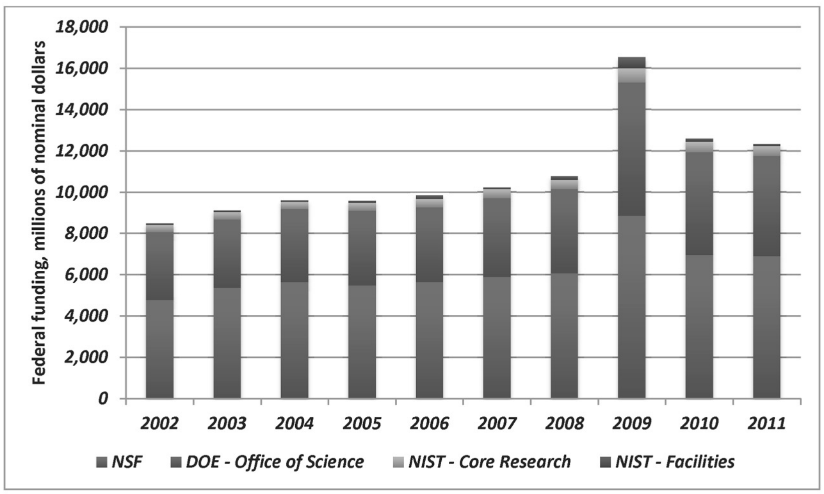
Source for figure & notes below: John F. Sargent Jr. (2012) "Federal Research and Development Funding: FY 2013," Congressional Research Service report, R42410, 15 June 2012.

Notes: "The 7-year doubling pace represents annual increases of 10.4 percent, the 10-year doubling pace represents annual increases of 7.2 percent, the 11-year doubling pace represents annual increases of 6.5 percent, the 15-year doubling represents annual increases of 4.7 percent, and the 20-year doubling represents annual increases of 3.3 percent. Through compounding, these rates achieve the doubling of funding in the specified time period. The lines connecting aggregate appropriations for the targeted accounts are for illustration purposes only. With respect to "Actual Appropriations," aggregate data for FY 2006–FY 2012 is based on regular appropriations (funding provided under the American Recovery and Reinvestment Act of 2009 (P.L. 111–5) is not included). America COMPETES Act figures are based on aggregate funding for the target accounts as authorized by the act. America COMPETES Reauthorization Act of 2010 figures for FY 2011–FY 2013 are based on aggregate funding for the target accounts as authorized by the act" (Sargent, 2012, p. 9).

Figure 2. Funding for "Doubling Path" accounts in millions of nominal (current) dollars, FY 2002– 2013

FY 2002–FY 2011 (Actual), FY 2012 (Estimated), and FY 2013 (Request)

FY 2009 combines funding from FY 2009 and the American Reinvestment and Recovery Act.



Notes: "NIST—Core Research" reflects funding for the "NIST-Scientific and Technical Research and Services" (NIST–STRS) account. Budget figures for this account and the "NIST—Facilities" account do not include items appearing under the "NIST—Industrial Technology Services" (NIST–ITS), which include programs such as the Advanced Manufacturing Technology Consortium (AMT), Advanced Technology Program (ATP), Technology Innovation Program (TIP), Baldridge Performance Excellence Program (BPEP), and Hollings Manufacturing Extension Partnership (MEP).

Source: FY 2002–FY 2005 data from NSF, DOE-Office of Science, and NIST annual budget requests (websites listed below); FY 2006–FY 2013 data from John F. Sargent Jr. (2012) "Federal Research and Development Funding: FY 2013," Congressional Research Service report, R42410, 15 June 2012. NSF budget data from *www.nsf.gov/about/budget/;* DOE–OS data from *science.energy.gov/budget/;* NIST budget data from *www.nist.gov/public_affairs/budget/*. Budget data taken from reports in FY+2 (*e.g.,* FY 2006 report used for FY 2004 budget data); JF verified that this method yielded match with budget data reported by Sargent (2012).

The CHAIRMAN. You will not go to jail, you know.

Thank you, Dr. Furman.

Now, Dr. Peter Lee, Corporate Vice President of Microsoft Research.

STATEMENT OF DR. PETER LEE, CORPORATE VICE PRESIDENT, MICROSOFT RESEARCH

Dr. LEE. Thank you, Chairman, Ranking Member, members of the Committee. Thank you for this opportunity. I am looking forward to sharing perspectives on research and education in the America COMPETES Act.

I have been pretty lucky. I have held leadership positions in some great research organizations, at Carnegie Mellon University, at DARPA, and now at Microsoft. This has allowed me to see first-hand the rich interplay between industry, academia and government, and how it creates an innovation ecosystem that creates a steady stream of ideas, technologies and talent that drives American competitiveness.

This innovation ecosystem, I do not think it came by accident. It rose out of an intentional and profoundly productive partnership between universities, industry and government.

On the nature of this partnership, I refer you to a recently released National Research Council report entitled "Continuing Innovation in Information Technology." This report illustrates, in fact, in the famous diagram referred to as the "tire tracks" diagram, how fundamental research in IT conducted in industry and universities over decades and supported by Federal agencies has led to the introduction of entirely new product categories that ultimately became the basis of new multibillion dollar job-creating industries.

Just a partial list of these industries includes broadband and mobile technologies, the Internet and the web, Cloud computing, entertainment technologies, robotics and automation.

Now, while the U.S. has demonstrated time and again the robustness of its IT innovation ecosystem, its current strength is not a guaranteed right but the result of American vision and sustained investment. The COMPETES Act is a key element of this.

So, what should the Committee be aware of as it begins the COMPETES reauthorization? I have two points to make.

The first is on the importance of investing in fundamental research. The multibillion dollar industries I mentioned earlier all rely on a pipeline of research advances enabled by our past investments. For example, decades of basic research in coding theory ultimately enabled today's smart phones, streaming video and an array of communications technologies. And, at Microsoft, our products and services today build on a pipeline of research advances in areas such as machine learning, distributed systems and computer graphics.

Looking forward, it is essential that we keep this pipeline full, so as to create new opportunities to contribute to the Nation's competitiveness. These include building on the ongoing interagency initiatives in big data and in robotics to advance transportation, energy, healthcare, and national security, as well as transforming education through personalized and online learning tools and systems.

Advances in basic research will also help us tackle grand challenges facing our society. For example, we must continue to focus on designing IT systems for security and robustness, while also developing the research that underpins privacy technologies and policies. Also important are advances in networking and mobile computing to support technology and policies around spectrum sharing for connecting people, devices, sensors and the Cloud.

Now, my second point is about people and investing in the future of people. Like all companies in innovation-based industries, Microsoft actively seeks to hire people with the skills and talent we need to be globally competitive. Yet, in August 2012, Microsoft had more than 3,400 unfilled research and engineering positions in the United States, a 34 percent increase from a year ago. And demand is predicted to go up: the Bureau of Labor Statistics estimates that, through the year 2020, there will be on average at least 120,000 job openings per year in computing professions that require at least a bachelor's degree. Yet, in 2010, only half that number of degrees were awarded in computer science in the United States.

It is not just people at IT companies or in IT jobs that should have the opportunity to study computing. Understanding, using and creating information technology matters for people involved in research and education, in STEM jobs in industries and governments, and in daily life.

Federal agencies should support efforts to expand computing education, particularly at the K through 12 level. Going beyond computing literacy, to an ability to think computationally, will be a cornerstone for the future workforce.

In conclusion, I believe that Federal agencies, companies and universities all play crucial roles in enabling American competitiveness. The reauthorization of the America COMPETES Act is an important element in providing Federal research agencies with the resources and guidance they need to sustain this innovation ecosystem.

Thank you for this opportunity to testify today and for this Committee's longstanding support for scientific discovery and innovation. I have additional information in my written statement and would be pleased to answer questions. Thank you.

[The prepared statement of Dr. Lee follows:]

PREPARED STATEMENT OF DR. PETER LEE, CORPORATE VICE PRESIDENT, MICROSOFT RESEARCH

Chairman, Ranking Member, and Members of the Committee, my name is Peter Lee, and I am a Corporate Vice President at Microsoft. Thank you for the opportunity to share perspectives on research, education, and the America COMPETES Act. I appreciate the time and attention the Committee has devoted to this topic, and I commend you for advancing the dialogue on innovation and competitiveness, including in information technology.

Microsoft deeply believes that investment in research and education lay the groundwork for advances that benefit society and enhance the competitiveness of U.S. companies and individuals. In my testimony, I will:

- describe the profoundly productive interrelationships between industry, academia, and government in the field of information technology;
- provide information and examples from our experiences and activities at Microsoft;
- mention some achievements that have occurred under the America COMPETES Act; and
- identify opportunities in computing research and education for the Committee to consider going forward.

My testimony today is informed by my experiences in academia, government, and industry. In the first area, I spent 22 years as a professor at Carnegie Mellon University, including serving as the Head of the Computer Science Department and as the Vice Provost for Research. Between Carnegie Mellon and Microsoft, I served in the Department of Defense at DARPA, the Defense Advanced Research Projects Agency. There, I founded and directed a technology office that supported research and developed innovations designed to keep our military at the leading edge in computing and related areas. Now, I hold the title of Corporate Vice President, Microsoft Research, where I am responsible for managing Microsoft Research Redmond, a laboratory of over 300 researchers, engineers, and support personnel dedicated to advancing the state of the art in computing and creating new technologies for Microsoft's products and services.

We're In This Together

My experiences in industry, academia, and government have given me a range of perspectives on the challenges and opportunities we face in sustaining a strong innovation ecosystem that not only is first to create new knowledge, but also is effective in deploying that knowledge to improve our society and security and maintain American competitiveness in the global economy. From the inside of some of our nation's best research organizations, I have seen first-hand how the rich interplay between industry, academia, and government produces a continuous stream of technological and business innovations. In a nutshell, our nation has been remarkably effective in supporting a productive, interconnected ecosystem of people, ideas, projects, and resources that today drive American competitiveness. The COMPETES Act is a prime example of this support.

I will focus specifically on the field I know best, which is information technology (IT). The commercial IT industry is a well-known and well-appreciated success story of American innovation and leadership. American ingenuity has turned advances in IT into an incredible driver for global competitiveness and economic growth. Today, IT contributes about 5 percent to overall U.S. GDP, according to the Bureau of Economic Analysis. Yet the success was not solely the outcome of visionary and very hard-working people at companies across the U.S., such as Microsoft. Instead, it is the result of a tightly interconnected ecosystem of people, ideas, projects, and resources from government, academia, and industry.

The nature of this complex partnership is illustrated in the recently released report *Continuing Innovation in Information Technology.*[1] (I chaired the National Research Council committee that produced this study.) The centerpiece of that report is a diagram, referred to as the "tire tracks." (See Appendix A.) This diagram illustrates how fundamental research in IT, conducted in industry and universities over decades, and supported by Federal agencies, has led to the introduction of entirely new product categories that ultimately became the basis of new billion-dollar industries, including broadband and mobile technologies; microprocessors; personal computing; the Internet and the Web; cloud computing; enterprise systems; entertainment technologies; and robotics. In all of these cases and more, there is a complex interweaving of fundamental research and focused development, with innovations in academia driving breakthroughs in industry and vice versa; with ideas and technologies transitioning among fields and applications, creating opportunities in both new research and new products and markets.

The three sectors of academia, government, and industry play complementary roles in ensuring the health of the innovation ecosystem. In particular, the study notes that "the government role has coevolved with the development of IT industries: its programs and investments have focused on capabilities not ready for commercialization and on the new needs that emerged as commercial capabilities grew." This evolving role of Federal agencies, and the research communities they support and nurture, is a critical complement to the activities of companies both large and small. Large companies, on the whole, are driven to invest more in product and process development, with clear connections to existing products and markets and planned rewards that can be demonstrated to shareholders in the near term. Start-up companies, while more open to potential new areas and opportunities, are focused on the implementations that make real the discoveries of past research, not on conducting new investigations.

Without research agencies and universities to focus on the ever-shifting frontiers of multiple computing sub-disciplines, to explore connections across disciplines and products, and to expose each generation of students to an array of future possibilities, companies will not have the reservoir of ideas and talent to maintain the U.S. lead in today's IT sector and build the next set of multi-billion dollar job-creating industries.

The U.S. has demonstrated time and again that the three components of the IT innovation ecosystem are each strong and the vital connections among them are robust. Yet this situation is not a guaranteed right. It is a result of sustained investment and a nurturing environment. Other nations have looked at the U.S. successes and are applying the lessons they have learned about how to invest in research, to nurture a culture of original discoveries at universities, and to deploy a legal and regulatory framework to encourage innovation. India and China both have made significant progress and are likely to benefit from having sizable internal markets for IT products. Other nations, such as Ireland, Israel, Korea, Taiwan, Japan, and some

[1] *Continuing Innovation in Information Technology;* Committee on Depicting Innovation in Information Technology; Computer Science and Telecommunications Board; Division on Engineering and Physical Sciences; National Research Council. *http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_045476.*

Scandinavian countries, are also developing strength in specific areas within various IT sectors.[2]

Microsoft Research

Microsoft is a direct beneficiary of, and wholly committed to, its role in the innovation ecosystem described above. This requires significant investments by us in various elements of this ecosystem. Across the company, more than $9 billion a year is directed toward research and development (R&D), with the vast majority of those funds supporting development activities focused on specific products. A critical element, although small in dollar terms, of our overall R&D investment is in more fundamental explorations at Microsoft Research (MSR). Founded in 1991, MSR is now the largest and highest quality industrial computing research organization in the world, with over 800 Ph.D.s working in more than 55 research areas. MSR is dedicated to advancing the state of the art in computing, often in collaboration with academic researchers and government agencies, and to creating new technologies for Microsoft's products and services. This organization and these people allow Microsoft to respond more rapidly to change and provide a reservoir of technology, expertise and people that can be quickly brought to bear to respond to and create new technologies, new competitors, and new business models.

While MSR activities are distinct from the short-term development activities conducted at Microsoft and other companies, distinctions such as "basic" versus "applied" don't really apply to computing research. In fact, computing research is a unique and intoxicating blend of invention, discovery, and engineering. MSR researchers collaborate with leading academic, government and industry colleagues and often move in and out of universities and Microsoft business groups as the type of activities they are engaged in shift in focus.

I like to say that within MSR we can see the incredible range of possibilities in computing research come alive. A recent example is Microsoft's Kinect, which allows you to control games by using your body and voice. The real achievement here is the creation of a system which recognizes people and their voices in a variety of environments, tracks and responds to their body motions in real time, and can be produced in bulk. The technology builds on decades of blue-sky and disruptive research, conducted both in academia and in MSR, in a range of areas including machine learning, image processing, audio processing, and natural language processing.

The impact of Kinect is just one example of the connections and synergies between industry and academia that are discussed in the *Continuing Innovation in Information Technology* and illustrates how information technology shifts and evolves from research to products back to research. By providing a flexible and affordable system by which visual and voice feeds can be processed and used by a computer, Kinect is already transforming a variety of academic research projects and applications in robotics, human-computer interaction, online education, and more. In addition, the advances originally targeted at the gaming and entertainment business are having multiplier effects outside the IT sector as the technology is investigated for deployment in retail (virtual car tours)[3] and for healthcare applications (such as autism or post-stroke physical therapy).[4]

The Demand for STEM Knowledge

Microsoft and MSR actively rely on a vibrant and effective education system within the national research environment to produce a pipeline of diverse and highly qualified graduates. MSR supports a variety of activities to strengthen this pipeline, including fellowships for students and early career professors and programs to increase the recruitment and retention of girls and women in computing. A key element of our deep connection with the community is our annual internship program. We bring over 1,800 student interns to Redmond each year, with over 300 in Microsoft Research. The MSR interns participate in cutting-edge research and also learn about how advances fit into the context of a company that must continuously provide innovative products to thrive. This experience helps prepare students for a variety of career paths—as professors, as entrepreneurs, as industry researchers, and some even as Microsoft employees.

A main reason that MSR, and Microsoft as a whole, devote significant attention to our internship programs is that the success of Microsoft is strongly dependent on the talent of our employees. We aggressively seek out talented people who will

[2] *Continuing Innovation in Information Technology, http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_045476,* page 11.

[3] More information about how the Kinect is being used in other commercial sectors is available at *http://www.microsoft.com/en-us/kinectforwindows/*.

[4] More information about how the Kinect is being used in healthcare, education, the arts, and other applications is available at *http://www.xbox.com/en-US/Kinect/Kinect-Effect.*

help build our company into one that is successful in improving our current products and creating new ones as we participate in the rapid change that characterizes our innovation-based economy. Yet in August 2012, Microsoft had more than 3,400 unfilled research and engineering positions in the United States, a 34 percent increase in our number of unfilled positions compared to a year ago. And predictions suggest that this situation could get worse. The Bureau of Labor Statistics estimates that between 2010 and 2020, there will be at least 1.2 million job openings in computing professions that require at least a bachelor's degree (on average 120,000 per year) and that in 2020 half of the over 9 million STEM jobs will be in computing.[5] Yet in 2010, only about 60,000 bachelor's, master's, and Ph.D. degrees were awarded in computer science[6]—far less than the predicted demand.

As information technology permeates many aspects of our day-to-day lives and becomes a critical element of sectors from manufacturing to healthcare, from retail to education, other companies too will be searching for the people with the core knowledge and creativity to reinvent how we do business and keep American companies at the forefront of the global economy. Just in the area of skills related to the explosion of "big data" in multiple industry sectors, the McKinsey Global Institute predicts a shortfall of 140,000 to 190,000 people with deep analytic skills (*e.g.,* in statistics and machine learning) and 1.5 million managers and analysts with the skills to interpret and make decisions based on the data analysis.[7]

Microsoft recognizes that many U.S. employers are searching for people with the skills and talent we need to be globally competitive. On September 27, Brad Smith, Executive Vice President and General Counsel at Microsoft, will speak in Washington, DC at the Brookings Institution on this issue and the policy changes necessary to foster an education system that provides opportunities for students to access the type and levels of education required to secure jobs in innovation-based industries.[8] We look forward to continuing the conversation on STEM education and policy with the Members of this Committee and the larger government, industry, and academic communities that all have roles to play in this important area.

Five Years of the America COMPETES Act

Since the America COMPETES Act was passed in 2006 and reauthorized in 2010, the agencies covered under the Act have made important contributions to advancing our fundamental understanding of the world and training the next generation of scientists and engineers. In computing, there are several achievements of the past five years that would not have been possible without key contributions by the Federal Government.

Research

Under America COMPETES, we have seen significant interagency collaboration on research targeted at major challenges and opportunities. Two recent examples are the initiatives in robotics and "big data." These both illustrate the interconnections between industry, academia, and government described above, as they are simultaneously areas for cutting-edge fundamental research on hard problems that will occur at universities and industry labs, and also the focus of development and deployment activities at large corporations and in the operations of government agencies.

The National Robotics Initiative was launched in June 2011. The focus is on "co-robotics"—enabling the development of robots that work with or beside people to extend or augment human capabilities, taking advantage of the different strengths of humans and robots. An important characteristic of the initiative is that it both supports core research in areas such as computer vision, language processing, and dexterous manipulation that will advance robotics capabilities across the board while

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[5] This estimate is based on the Bureau of Labor Statistics' occupational employment and job openings data, projected for 2010–2020, *http://www.bls.gov/emp/*. Further analysis of the computing jobs predictions are available from the Association of Computing Machinery, *http://cacm.acm.org/blogs/blog-cacm/147077-computer-science-jobs-and-education-presentation-slides/fulltext.*

[6] From the Integrated Postsecondary Education Data System from the U.S. Department of Education's National Center for Education Statistics, available at *https://webcaspar.nsf.gov.*

[7] Report from McKinsey Global Institute, *Big data: The next frontier for innovation, competition, and productivity,* May 2011, by James Manyika, Michael Chui, Brad Brown, Jacques Bughin, Richard Dobbs, Charles Roxburgh, Angela Hung Byers. *http://www.mckinsey.com/Insights/MGI/Research/Technology_and_Innovation/Big_data_The_next_frontier_for_innovation.*

[8] Brookings Institution Event on "Education and Immigration Reform: Reigniting American Competitiveness and Economic Opportunity" on September 27, 2012. See *http://www.brookings.edu/events/2012/09/27-stem-education.*

also supporting research targeted at key robotics applications in areas such as health, manufacturing, agriculture, defense, and space exploration.

The Federal Big Data Initiative was launched in March 2012. This initiative builds on many years of research at multiple agencies to improve the creation, management, analysis, fusion, visualization, understanding, and use of very large data sets. Advances in these areas will improve scientific research (*e.g.,* on disease or the environment) and facilitate real-time decision making (*e.g.,* in the defense and intelligence sectors or electricity grid management). Increasing the ability to generate and interpret big data is already having an impact in diverse sectors, from retailing to healthcare[9], and Federal investment will create new capabilities with even broader benefits. At Microsoft, as well as our industry competitors, we are making big bets on Big Data. Already, today, nearly every product and service offered by Microsoft is improved or enabled by computing research advances in an area called machine learning, which pertains to the design of systems that become more effective with experience. Today, that "experience" is gained through the analysis of big data. Whether it is the analysis of large numbers of electronic health records to improve patient care for individuals, or the use of massive amounts of training data to improve how well Kinect can track a videogame player's movements, advances in big data provide a critical foundation for our products.

Another emerging example can be found in research on how large numbers of interconnected people and computers can be used together to solve hard problems. While I was at DARPA, I led an experiment to see if social networks could be used to rapidly mobilize very large numbers of people to conduct coordinated operations at global scale. The resulting "red balloon hunt" (officially called the 2009 DARPA Network Challenge) inspired millions of people around the globe to collaborate. This experience had a major impact on thinking within the Department of Defense. Another approach to this phenomenon can be seen in FoldIt, which was also supported while I was at DARPA. FoldIt is a crowdsourced computer game for protein folding and protein structure calculation, and last year it was used to solve an AIDS-related protein structure problem whose solution had eluded the scientific community for a decade. At Microsoft and other companies, some products and services, such as search engines, are improved as more people use them, a form of crowdsourcing. While we have embarked on early research into the potential of such online task markets, we rely on new government research programs, for example on "social computing," to build a coherent research community and pool of talented researchers to collaborate with and hire.

Education

A key attribute of the America COMPETES Act and its reauthorization is the recognition of the importance of every element of the system that contributes to science, technology, engineering, and mathematics (STEM) education in the U.S. From K–12 to undergraduate, from graduate education to post-doctoral studies and early career faculty, Federal programs have an opportunity to improve the approaches taken in schools and universities to ensure rigorous and engaging courses are offered and students have the opportunity to experience and explore the STEM fields.

Two examples of recent programs that supported the goals of America COMPETES are Computing Education for the 21st Century (CE21)[10] and the Computing Innovation Fellows (CIFellows),[11] both out of the National Science Foundation.

The CE21 program focuses on generating knowledge and activities related to computing education with the goal of building a robust computing research community, a computationally competent 21st century workforce, and a computationally empowered citizenry. Examples of work underway in this program include development of resources to facilitate expansion of computer science teaching in high school, such as the design assessments and models of teacher professional development for new courses, including a new computer science AP course, research on the teaching and learning of computational competencies, and alliances to broaden participation in computing careers. CE21 is ongoing and continues to provide important contributions necessary to advance computing education in the U.S.

The CIFellows Program is a program that ran from 2009 to 2011 and was a targeted response to concerns that the economic climate in 2009 would force a large

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[9] The McKinsey Global Institute Big Data report referenced above analyzes the potential impact of big data on five domains, including manufacturing, retail, and public sector administration.

[10] The National Science Foundation's Computing Education for the 21st Century (CE21) program is described at *http://nsf.gov/funding/pgm_summ.jsp?pims_id=503582.*

[11] Information about the Computing Innovation Fellows Project is available at *http://cra.org/ccc/cifellows.*

number of new Ph.D.s in computer science and related fields to delay or altogether abandon a research career in academia or industry. By providing post-doctoral fellowships, which historically had been less common in computing than other fields, and matching awardees to mentors, the CIFellows program provided interim employment and career development at a critical juncture where the research workforce pipeline was in danger of breaking down. It is still early to fully assess the impact of this program, but many of the CIFellows have now found permanent employment in research organizations (including at Microsoft Research) where they can contribute to the innovation opportunities outlined elsewhere in this testimony.

Looking Ahead

As a nation, we can be proud of the achievements that occurred under the past five years of America COMPETES, but there are still research questions to be answered and societal challenges in technology and education to be tackled. The activities of the past lay the groundwork that we can build on going forward. Below I provide several observations about the opportunities that exist for the Committee to consider as it begins reauthorization of the America COMPETES Act.

Invest in the future of research

The impact and results of research are often unknown when the research is started. The value and payoff of a sustained and healthy investment in research is often realized well after the initial work is done. Today, the U.S. is reaping the benefits in both our quality of life and in the global competitiveness of our companies that builds on past investments. According to estimates by the Bureau of Economic Analysis, the IT-intensive "information-communications-technology-producing" industries grew by 16.3 percent in 2010.[12] The strength of these industries are built on research in many areas over many years. One example is research on coding theory that eventually enabled modern cell phones and streaming video through the Internet.[13] Another is the research on distributed computing, including in software, storage, and networking, that provided the underpinning of today's rapidly-expanding cloud computing industry, in which the U.S. is the international leader.

Grand Challenges and Computing Research: To maintain American leadership in a world where information, knowledge, and people move rapidly around the globe, the U.S. must support research in all disciplines of science and engineering. Many of the grand challenges facing society require not a single breakthrough in a single area, but the contributions of researchers in multiple fields and the integration of new knowledge into complex systems. Computing is often a central element in tackling these grand challenges and improving healthcare, transportation, education, national security, energy independence, scientific discovery, and prosperity. Looking ahead, examples of the opportunities that exist include:

- Advances in big data and robotics targeted at refining and reimagining our transportation and energy systems to improve reliability, safety, and efficiency.
- Continued focus on designing IT systems for security and robustness in light of different levels of risk and threat posed by different applications and environments.
- Advances in networking and mobile computing to enable next-generation technology and policies around spectrum sharing[14] in order to provide the global connectivity among people, devices, sensors, and the cloud that will allow benefits in areas such as continuous health monitoring and smart buildings and cities, as well as expand access to information and technology throughout the world.
- Technical and social science research to underpin privacy technologies and policies.
- Integrating IT capabilities with educational knowledge to deploy personalized or just-in-time learning tools and systems that improve networks and information for teacher and schools.

[12] *Continuing Innovation in Information Technology, http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_045476,* page 1.
[13] *Continuing Innovation in Information Technology, http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_045476,* page 11.
[14] The potential benefits of spectrum sharing and the associated policy and technical issues are described in *Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth,* President's Council of Advisors on Science and Technology, *http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf.*

Cyberinfrastructure: New technologies from computing have always played a key role in enabling discoveries across multiple fields of science and engineering. Today, modern science increasingly relies on integrated information technologies and computation to create, collect, process, and analyze complex data. Federal agencies must continue to support research and deployment activities that facilitate effective use of cyberinfrastructure [15] in ways that recognize the changing scale and types of scientific information and the rise of the "fourth paradigm" of data-intensive science.[16]

Interagency Coordination and Existing Legislation: Information technology research and education is a critical element within the mission and activities of multiple Federal agencies, and the interagency Networking and Information Technology Research and Development (NITRD) program has for years facilitated the coordination of these activities. The President's Council of Advisors on Science and Technology (PCAST) report on *Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology,*[17] and the upcoming PCAST update of that report, clearly articulate the opportunities in NIT and recommendations for moving forward. Microsoft is supportive of the reauthorization of the NITRD program, whether as part of the COMPETES reauthorization or as stand-alone legislation.

Invest in the future of people

Technology, including information technology, is permeating society. Citizens of the 21st century will need core analytical and quantitative knowledge to manage every-day tools such as smartphones and programmable thermostats, to fill well-paying jobs in multiple technology-dependent industrial sectors, and to create the new technologies that fuel the innovation economy. The Federal agencies have key roles to play in ensuring that students today receive the education they need for society to thrive in the years ahead.

Computing Education: As discussed throughout this testimony, understanding, using, and creating information technology is key for people involved in research and education, in STEM jobs in industry and government, and in daily life. Agencies should support efforts to expand computing education, particularly at the K–12 level, and ways to increase exposure to computing education and research opportunities at the university level, for both computing majors and those in other disciplines.

At the K–12 level, good work has been done to date in universities on courses and professional development (as mentioned above) and advances have been made in some states and cities. Yet still only nine states allow computer science courses to count as part of the "core" curriculum that students can choose to pursue to graduate from secondary school.[18] More information about the opportunities and policy challenges is available from the Computing in the Core coalition (*http://www.computinginthecore.org/*), of which Microsoft is a founding member.

At the higher education level, it is important that the system have the capacity to expand to serve a hopefully growing number of people wishing to study computing. Also important is that the content and approaches used in college computing courses reflect what is being learned about engaging and effective learning and up-to-date content in rapidly-changing areas such as cybersecurity.

In addition to activities that support these goals specifically, it is important that general Federal "STEM" programs—whether for teacher development and support, pedagogy research, undergraduate education, or other areas—recognize that computer science is included in their purview and clearly enable its inclusion through their solicitations, outreach, and review criteria. While the importance of including computer science in STEM has been widely recognized for several years, accomplishing this may require coordinated action by government agencies.

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[15] The role of networking and IT infrastructure in research in other fields is discussed in *Designing a Digital Future: Federally Funded Research and Development Networking and Information Technology,* President's Council of Advisors on Science and Technology, *http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf.*

[16] Further discussion of the impact of advanced computing capabilities on multiple fields of science is available in *The Fourth Paradigm: Data-Intensive Scientific Discovery, http://research.microsoft.com/en-us/collaboration/fourthparadigm/default.aspx.*

[17] *Designing a Digital Future: Federally Funded Research and Development Networking and Information Technology,* President's Council of Advisors on Science and Technology, *http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf.*

[18] Eight states count computer science as a mathematics credit—Missouri, New York, North Carolina, Oklahoma, Oregon, Rhode Island, Texas, and Virginia—and one (Georgia) counts it as a science credit. CSTA, ACM (2010). *Running On Empty: The Failure to Teach K–12 Computer Science in the Digital Age.* Available at *http://www.acm.org/runningonempty/.*

Education Across Disciplines and Integrated with Research: The pace of change and discovery in science and engineering is increasing, as is the amount of work involving researchers from multiple disciplines. Universities are well-positioned to respond to these trends, and Federal agencies should continue to support and drive universities to enable students to engage in interdisciplinary courses of study and also to develop opportunities and resources for students to access courses and knowledge from outside their primary area of study. Also it is important that we preserve and build on the integration of research and education that is possible within the U.S. research university system for undergraduates and graduate students. This exposes students to the cutting edge of rapidly changing fields and, through those students and their post-graduation employment in industry and elsewhere, improves the transfer of knowledge from academia.

Diversity: The demographics of the Nation are changing. Society benefits when people have access to multiple fields and career choices. Women and certain minorities have historically been underrepresented in many science and engineering fields, including computing. A number of efforts are underway to shift this situation, and we all must continue to strive to improve diversity in science and engineering.

Summary

- Past investment in computing research has spawned multiple new billion-dollar IT industries that have significant positive impact on the U.S. economy.
- Advances in IT are also enabling innovation in multiple sectors (such as manufacturing, healthcare, energy, education, and retailing).
- Innovation in IT results from an interconnected ecosystem in which government, universities, and industry each play a critical role.
- Federal investment in research is a critical component of tacking national challenges in transportation, health, energy, education, and other areas. This will require support for both multidisciplinary research and strong investments in advancing the core of all research areas, especially computing. It will also require support for the development and deployment of cyberinfrastructure.
- People will need STEM skills, especially computing knowledge, to be citizens, employees, and innovators in the 21st century technology-infused world.
- Strengthening the pipeline of STEM education, including computer science education.

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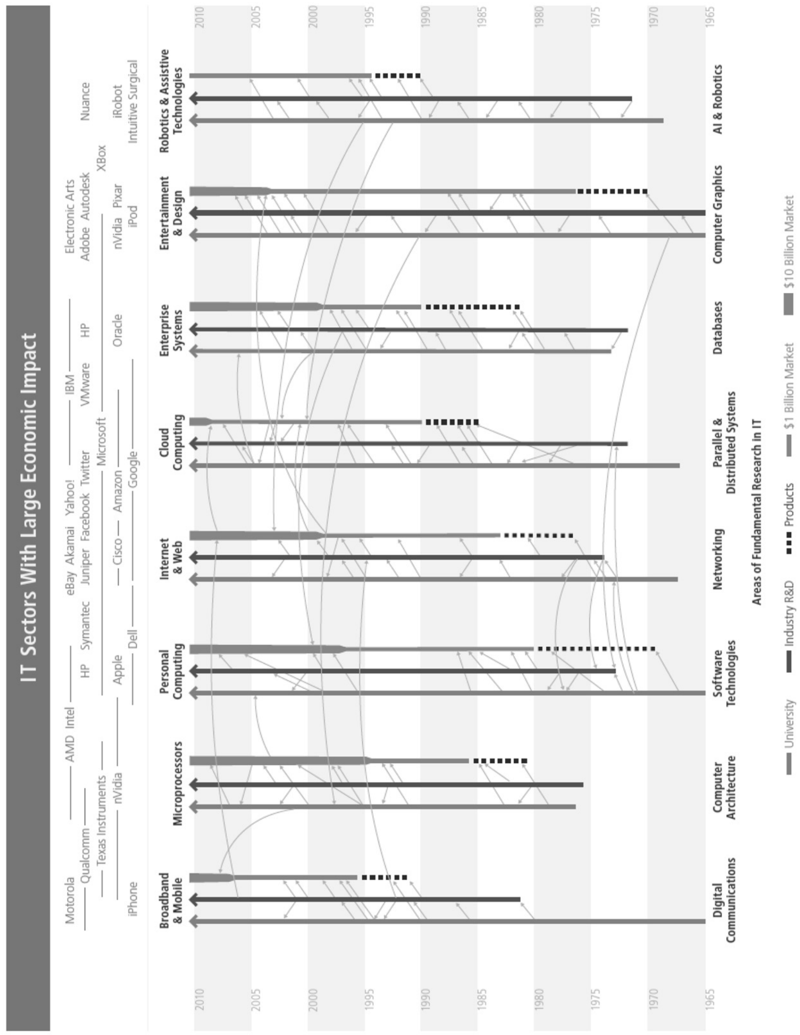
In conclusion, I believe that Federal agencies, companies, and universities all have major responsibilities in the interrelated system by which curiosity becomes discovery, and knowledge is deployed for the sake of the Nation's competitiveness and society's well-being. The reauthorization of the America COMPETES Act is an important step toward providing Federal research agencies with the resources and guidance they need to contribute to our innovation ecosystem.

Finally, let me thank you for this committee's longstanding support for scientific discovery and innovation. I would be pleased to answer any questions you might have.

Appendix A: The Tiretracks Diagram



This is Figure 1 from National Research Council, *Continuing Innovation in Information Technology,* National Academies Press, Washington, D.C., 2012. Full report is available at *http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_045476.*

WITNESS BIOGRAPHY—PETER LEE—MICROSOFT

Dr. Peter Lee holds the title of Corporate Vice President, Microsoft Research. In this position he is responsible for managing Microsoft Research Redmond, a laboratory of over 300 researchers, engineers, and support personnel dedicated to advancing the state of the art in computing and creating new technologies for Microsoft's products and services. Prior to joining Microsoft, Dr. Lee was a professor at Carnegie Mellon University. A devoted teacher and a researcher with over 100 research publications, distinguished lectures, and keynote addresses, he served as the Head of CMU's Computer Science Department and before that had a brief stint as the university's Vice Provost for Research. Peter Lee also served in the Department of

Defense at DARPA, the Defense Advanced Research Projects Agency. There, he founded and directed a major technology office that supported research in computing and related areas in the social and physical sciences.

Peter Lee has shown executive-level leadership in world-class research organizations spanning academia, government, and industry. He is a Fellow of the Association for Computing Machinery and serves the research community at the national level, including policy contributions to the President's Council of Advisors on Science and Technology, membership on the National Research Council's Computer Science and Telecommunications Board, former chairmanship of the Computing Research Association, and testimony before the U.S. House Science and Technology Committee.

The CHAIRMAN. Thank you very much, Dr. Lee.

And now, Mr. John Winn, Chief Program Officer, National Math and Science Initiative. Please.

STATEMENT OF JOHN L. WINN, CHIEF PROGRAM OFFICER, NATIONAL MATH AND SCIENCE INITIATIVE

Mr. WINN. Thank you, The Chairman, members of the Committee. I am indeed honored to testify before you today on behalf of Tom Luce, our Chairman and CEO in the National Math and Science Initiative.

The CHAIRMAN. Can you pull that mike up toward you a little bit? Thank you.

Mr. WINN. Thank you. I would like to express our gratitude for all the good work that went into America COMPETES Act. We think it is extraordinary legislation and support it. Tom Luce, as well as the rest of us, would like to extend our special thanks and gratitude to Senator Hutchison and her great work to further the competitiveness of this nation, and particularly in STEM education.

Since its inception five years ago, the National Math and Science Initiative has been replicating proven programs in STEM education, both in teacher preparation, as well as in advanced STEM learning within K–12 education.

We believe that, through public-private partnerships, and through provided guided replication and implementation of successful programs in public schools and universities who desire to, not only change STEM education, but to transform STEM education in an important and powerful way, is indeed an incredible mission.

One particular program that we replicate is the UTeach program that Senator Hutchison mentioned earlier. This program was created by the University of Texas in Austin, and it recruits STEM majors into a integrated program of science, mathematics, engineering, as well as providing them with education credentials, all within a four-year period. There are many programs that provide two degrees, but most of them require an additional year of education.

Ninety percent of our UTeach graduates go directly into teaching, and 80 percent of our graduates, our teachers that are in the field, are still teaching in STEM fields five years later.

To implement UTeach successfully, it requires a close relationship between colleges of natural science and colleges of education. Can you imagine a senior engineering professor teaching alongside a college of education professor or a master teacher? You really do not have to, because you can see it in action at the University of

California at Berkeley, and at many other UTeach sites across the Nation.

We now have 33 universities across the nation implementing UTeach. I will refer you to the map that is included in my written testimony.

UTeach works in all sorts of universities, Research One universities, comprehensive, rural and urban settings. These universities that are replicating UTeach now have over 5,500 actively enrolled students who we believe, that by 2020, will have taught over four million public school students in STEM education.

As Senator Hutchison pointed out, this Act authorizes to replicate and implement programs in institutions of higher learning that have integrated course of study in science, technology, engineering and mathematics, and teacher education. This describes UTeach perfectly.

UTeach, we believe that there are unfilled opportunities in America COMPETES Act to make this subtitle a reality. The National Science Foundation rightly allocates funding for research and innovation across this nation. We think, by taking a broad view of the implementation of research and innovation, it can support the UTeach program and programs like it.

The UTeach program furthers research in two ways. Number one, in universities that are replicating UTeach across the nation, we are seeing a new wave of research in STEM teaching and learning that bubbles up at the faculty level. These research activities, many of them are small and within universities, but they are happening as a result of the replication of the UTeach program and are not dependent on external additional funding.

The second way that it supports research is the UTeach graduates become very adept at introducing research understanding and practice within the K–12 school system. What better way could we inspire students to go into more advanced study in STEM education than to have them involved in active research?

Also, the UTeach programs involves innovation, ongoing innovation, within the universities that are implementing it. By this I mean, although there are core elements of success that are followed for the integrity of the program, it requires a transformation within the universities that create new integrated curricula, develop new partnerships and new strategies for integrated teaching, both among STEM faculty and among college of education faculty.

In conclusion, I would like to share with you a situation that I noticed in Florida, when I was Commissioner of Education. We could never set the passing score in our mathematics and science certification test at the level that our best teachers recommended. Why? The reason was simple. We had too few candidates who could pass that high level.

I think this stands as a stark reminder that we need to produce a new generation of highly competent STEM teachers if we are going to reach our national goals.

Thank you.

[The prepared statement of Mr. Winn follows:]

PREPARED STATEMENT OF JOHN L. WINN, CHIEF PROGRAM OFFICER, NATIONAL MATH AND SCIENCE INITIATIVE

Good afternoon, Mr. Chairman and honorable members of the Committee. I am honored to be testifying before you today. I would like to say thank you for your support of innovation in STEM fields and would especially like to say thank you to Senator Hutchinson for her work to offer solutions to this Nation's growing need to become more competitive in a highly technological world. We will certainly miss you.

Today I am testifying on behalf of the National Math and Science Initiative located in Dallas, Texas. Since its inception five years ago, NMSI has been replicating successful programs to transform STEM teaching and advanced learning. Our approach relies on public private partnerships, performance management of replication and continued guidance and support for public schools and universities that have a strong desire, not just to improve STEM learning, but to transform it in a way that is powerful and lasting.

One particular program is UTeach, a teacher preparation program first developed at the University of Texas at Austin. This program is highly innovative in that it offers service minded majors in math, sciences, and engineering an opportunity to earn a degree in their field of interest and become a highly competent teacher all within four years. Ninety percent of UTeach graduates go directly into teaching and 80 percent continue teaching five years later. Their trademark is a strong knowledge of their subject and four years of teaching practice before they enter classrooms.

UTeach requires a close and lasting partnership between colleges in STEM fields of study and colleges of education. Can you imagine a senior engineering professor teaching UTeach classes beside a master teacher or senior education professor? You don't have to. You can see it at the University of California Berkeley and other UTeach sites across the Nation. We now have 33 universities replicating the UTeach program. I refer you to the map contained in my testimony. UTeach works in all types of universities: research, comprehensive, urban, and rural. These universities now have over 5,500 students actively enrolled and we project that over four million K12 students will have been taught by UTeach graduates by 2020.

How does this relate to the America Competes Act?

The Act authorizes a program at the National Science Foundation to "replicate and implement programs at institutions of higher education that provide integrated courses of study in science, technology, engineering, or mathematics, and teacher education . . ."

Subtitle B Section 551 states,

> *The purpose of this subtitle is to replicate and implement programs at institutions of higher education that provide integrated courses of study in science, technology, engineering, or mathematics, and teacher education, that lead to a baccalaureate degree in science, technology, engineering, or mathematics with concurrent teacher certification.*

UTeach is just this type of program. We believe that there are unfulfilled opportunities to make this statute a reality.

The National Science Foundation rightly allocates funding to spur research and innovation. With the strong support of this committee and taking a broad view of these priorities, the UTeach program can be supported as described in this legislation.

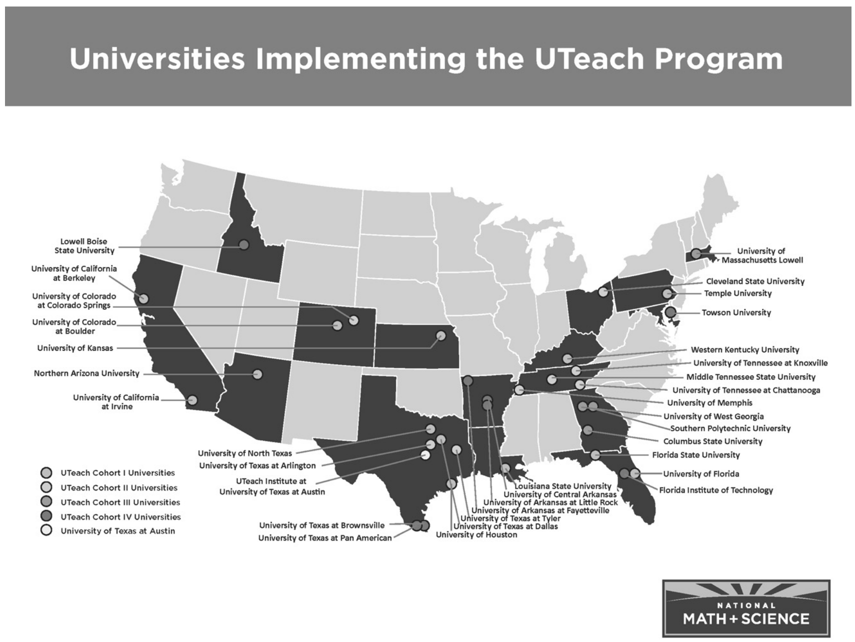
Support for research and innovation does not have to be limited early development. If we truly want to build a top flight generation of scientists, mathematicians, researchers, inventors, etc., we must lay the groundwork now. UTeach students learn to bring research understanding and practice into the K12 classroom. How better can we prepare and inspire students to go into advanced STEM fields and further our strong competitive presence? The universities replicating UTeach are starting a new wave of faculty driven research into STEM teaching and learning. Therefore, support for expanding UTeach is expanding research without additional funding.

There is no doubt that UTeach is a remarkable innovation. But it is not a program that can be adopted in a flash. Success requires four years of continuous innovation within the replicating university. New curricula must be collaboratively developed, new approaches to recruiting STEM majors into the program must be created, as well as developing additional relationships that make the program work. Although replication includes core elements of success, these unfold in ways often unique to the university.

One thing we all know. We can and must do better.

I would like to end by relaying a situation that underscores the need to transform STEM teaching. In Florida, we could never set our science and math certification exam passing scores at the level recommended by our best teachers. The reason is simple; there would be far fewer candidates passing the higher qualifying score. This phenomenon is not limited to one state. It is pervasive and it stands as a reminder that we need a new generation of highly trained STEM teachers if we are to reach our goals.

Thank you for your attention.



The CHAIRMAN. Thank you, sir.

In my opening statement, I referred to three main points, the last of which was the development of innovation infrastructure. As I was listening to the five of you, and also thinking, universities are not rapid in changing the direction of their battleships, and I have experienced in my own state the programs at major universities where there have been a tradition of how institutes are handled, and sometimes one person in the faculty, in the health sciences faculty for example, has responsibility for 19 institutes. That has not changed in some 10 years. I consider that not useful.

So, I want to give you a chance, any of you, I guess starting with you, Mr. Augustine, in talking about developing infrastructure, sort of going against what my argument with that was, getting away from the individual but developing infrastructure, whether, in fact, not the Stanfords and the Cal Berkeleys, et cetera, et cetera, but the upper-grade institutions across the rest of the country who now can participate, and very usefully and happily in America COMPETES and, therefore, research, whether—I mean, one could make the argument that we are overproducing biologists and we're under-producing petroleum engineers, and institutions, presumably local to that requirement, would seem to want to translate the way they do business.

I am just not sure that universities are any faster at changing the way they do things. Well, they are obviously faster than government agencies. But, you understand my point. And, I would love to have you comment, each of you, on that.

In other words, sort of getting back to the individual, which is what you suggested.

Mr. AUGUSTINE. I would be happy to comment. As you spoke, I am reminded of a situation that occurred at MIT when I was trying to help the provost there introduce a new program in systems engineering that cuts across the traditional departments of the university or the institute, and we were having a very hard time doing it. The faculty fought it, and the provost and I were getting very discouraged.

He took me aside and he said, "You know, Norm," he said, "the thing that you do not appreciate is how difficult it is to overcome 100 years of excellence and success." That is kind of what we are facing. Our universities have been so excellent and had such great success, that it is very hard to persuade them to change.

On the other hand, when one is looking at catastrophe, one tends to be much more adaptable. In the aerospace industry, we went through a period where we were looking at catastrophe, and we did many things that none of us would have wanted to do before. Briefly, we lost 40 percent of our employees and 75 percent of our companies in about five years, totally revamped the industry.

I think particularly with technology, this new wave of technology, it would just overwhelm our universities, unless they do change. So, I think it will be difficult, but I think it will come about.

With regard to your point how will we deal with the fact we produce too many biologists and maybe not enough petroleum engineers or what have you, I always like to say that, if we do not fund biology research adequately, we will produce too many biologists. But, the students seem to be very quick to adapt to market opportunities, and we saw that in computer sciences, where they do change quickly and move into fields that are needed, if they can. And, if they can is the major point, that we have heard that just too few of our students are qualified to study any kind of engineering or science.

The CHAIRMAN. One more person. Dr. Lee, perhaps you.

Dr. LEE. So, I think this point you are raising, I agree with Mr. Augustine, is a crucial one. I think in research there is a fundamental tension between, on the one hand, stability, and I think the commitment to big ideas and trying to protect possibly fragile concepts and ideas that might take a long time of investment to really understand on the one hand. And then, on the other, trying to be agile and react to obvious emerging societal challenges and needs. And, managing that tension, I think, is part of the game here, part of the challenge that we face.

By and large, I think that universities can and have done a good job in finding the right balance between the tension between stability and agility. If we take the current activities in online education, there are many, many scenarios. Several of us on the panel have stated that there could be huge transformations afoot.

But, we have also all been in this job long enough to know that, roughly every 5 years, the next big thing in online education that will transform universities kind of hits everyone's minds, and there is a big flurry of activity. And then, a more considered and deep exploration of these things occurs. Those things have, on occasion, transformed universities, going back to the complete wiring and putting every student on the Internet in the 1980s.

So, on balance, I would say that universities have demonstrated reasonable stability, but also an ability to adapt to new conditions.

The CHAIRMAN. OK, I will follow that up further, but my time is out. And now it is Ranking Member Hutchison, please.

Senator HUTCHISON. Yes, I would like to go to Norm Augustine again and ask in the "Rising Above the Gathering Storm" report, I have read it, and I know we fashioned legislation guided by it, but what do you think was not done that should be done? What would you do beyond America COMPETES when we are looking at a reauthorization? But, let us stipulate that we know putting more money into our appropriations where the authorizations have been made is a given. We understand that is a given, and it should be a priority in our limited budget. But, in the substance of where we should go, what would be your recommendations?

Mr. AUGUSTINE. Well, I would reiterate that we should implement the 20 recommendations that were included in the Gathering Storm" report, fully implement them. We got a good start, and then our progress waned.

I think a couple things. One thing we could do that costs very little, if any, money, and that is to try to help our young people understand the impact of science and engineering, the importance of it. I find it ironic that young people look with disdain on science and engineering, consider science and engineers to be geeks, but yet they all carry iPhones, and video games, and so on. So, that would be one thing we could do.

The other thing that I think is really new that needs to be added is some means of addressing the impact that the economy is having on our great universities. As I said, we did appreciate that when we did the "Gathering Storm" report. We could have imagined it. But today, those universities really are endangered, and I think that would be the main thing that I would encourage that be included as you revisit the Competes Act.

Senator HUTCHISON. You mentioned the higher cost of higher education as being one of the issues, and of course, certainly affordability is an issue. But, how would you attack that? We have tuition going up because costs are going up. You want research, although some Governors are saying in their states that research is not important. You want teachers in the classroom. I think that is shortsighted myself. But, it seems to me that the research is the spark that shows the students how exciting science can be. But, how would you bring down the costs if you do value research as well as teaching?

And, let me make a second point. Banks used to give student loans, but the Federal Government sort of took that over, and it is not in the private sector anymore like it had been. Do you think that has prevented more students from having the capability to get the loans that are necessary to bridge that gap of expense?

Mr. AUGUSTINE. You raise a number of important points. In my view, one of the elements of success of America's higher education system has been that our teachers are researchers, that they do both, and that there is a need for a balance. The private sector used to do a lot of research, some great basic research. Bell Labs would be an example.

I think there are things that you could do to change the tax laws that would encourage industry to invest more in research. Very simply, for example, if a person holds an asset for one day, the tax on the gain on that asset would be 99 percent. If they held it for 10 years, the tax would be 1 percent, and you would draw some kind of a line between the two. CEOs would act very differently in that world from the way they act today in terms of their willingness to support university research.

Also, how do you make universities more effective or more efficient? I think technology is part of the answer. We can draw on much more of technology for our teaching. Dr. Wieman has done a good deal of research in this area that I think offers great promise.

Therein, I cannot help but say this, that there are some very fundamental issues for our universities. One is their reason for existence. During the period that faculty salaries have been reduced, as they have the last couple of years on average, we have vastly increased pay of the football coaches. We need to think through what it is we want our universities to do.

Senator HUTCHISON. Yes, please, Mr. Wieman.

Dr. WIEMAN. If I could just make a brief comment on this. I think one of the things you really need to look at is something Norm talked about early on, is the fully funding of research. This is something I have spent a lot of the last year looking into and could give you detailed numbers. It takes a lot of digging.

But, if you just look at the AAU institutions or 25 top research universities, they are actually spending $5,000 per undergraduate per year to subsidize research costs with probably 50 to 60 percent of that going directly to cover unreimbursed costs associated with federally funded research. The agencies do not want to talk about this and the universities do not want to talk about this, so it is all kind of hidden. But, these unreimbursed costs are coming out of tuition. If you track it down, that is the only place it can come from.

So, the result is, if you go and give big increases to the research funding, you are actually making college less affordable. Harvard, Stanford, et cetera, they have plenty of money to pay for this, and they can charge whatever tuition they want. The good state universities are the ones really getting hurt by this, and this is part of what is causing the financial problems they have. But, the administrators at those schools cannot admit that they are taking money out of student tuition topay for research, because they would all get fired. It is a serious issue you need to look into.

Senator HUTCHISON. I am so sorry. I do not understand exactly what you were saying. That more Federal research funding hurts the universities because of hidden costs?

Dr. WIEMAN. Yes. It is the hidden unreimbursed costs. For example, you know, NIH has hundreds of millions of dollars for graduate fellowship programs. They set a cap on that program of 8 percent to cover indirect costs. If you look at what the government feels are the actual costs of supporting and maintaining a research graduate student, and what they will pay in indirect costs on a regular research grant, it is about 50 percent higher than that.

So, if I am in a university, and I have a student who gets a NIH fellowship, my university has to pay. It has to find money somewhere to actually cover about 50 percent of the real cost of that student. If I am a dean, I am faced with a choice of saying, "Oh, we are going to start turning down Federal fellowships and research grants, because they are not being paid for," which would be a terrible thing for a dean to say. They would get fired immediately. Or they say, "I have got to find money somewhere else that nobody is going to notice to pay for this," and that other place, for state universities now, is tuition.

Senator HUTCHISON. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you.

Senator Udall from New Mexico, and then Senator Thune from South Dakota.

STATEMENT OF HON. TOM UDALL, U.S. SENATOR FROM NEW MEXICO

Senator UDALL. Thank you, Chairman. And, I know you have noted that this was probably the last hearing for our Ranking Member, Senator Hutchison, and I just want to thank her for all of her good work for this Committee, and just really solid, I think, bipartisan effort in all of the markups we have had and the progress we have made. The two of you working together have been a great team. So, we are going to miss her a lot. And, I particularly enjoyed working with her on the Mexico-U.S. parliamentary group, with the Senate coming up, and many, many other things. But, thank you for your service, and I think we are going to miss you very much.

Senator HUTCHISON. Thank you.

Senator UDALL. You bet. You bet.

Dr. Wieman, I would like to ask you, sir, for your specific thoughts on improving STEM education for girls and how to encourage more young girls to pursue careers in STEM fields. One National Science Foundation reports that women earned only 21 percent of doctoral degrees in computer science, and many women who earned science, engineer and math degrees are not hired in STEM fields. Research from the National Association of University Women suggest that this disparity threatens our ability to innovate and compete globally in these fields.

What Federal policies would improve our nation's efforts to attract and retain women in STEM fields?

Dr. WIEMAN. That is a difficult issue, and it extends beyond women, to other underrepresented groups, of course.

Senator UDALL. You bet. You bet. And, you can expand out a little on that. That would be fine.

Dr. WIEMAN. What we do know is these improved teaching methods help it. We have good data from colleges and universities that these improved teaching methods have a disproportionately large impact on underrepresented students. And, I could go through in detail why they better relate to and help with the particular challenges of such groups, because they are better targeted to a student's prior experiences, background, and so on.

But, getting above that into the broader issues of employment and so on, a lot of those things are determined by broader, cultural aspects. So, Federal efforts are always going to be somewhat limited in what they can do. But, there are very clear things that have been demonstrated; research that shows ways to change teaching that make it much more effective and successful for underrepresented groups. This is based on having a deeper understanding of the learning process, and the way the students' experiences, and the differences in those experiences shape their classroom experience.

Senator UDALL. Thank you.

Dr. Furman, in your testimony, you described the creation of the Advanced Research Projects Agency for Energy, called ARPA–E. And, as one of the successes, and you know this as one of the successes of America COMPETES, ARPA–E which funds breakthrough energy technology development. However, with the looming sequester, the DOE Office of Science may be cut by $400 million. DOE's Office of Renewable Energy and Energy Efficiency could see $150 million in cuts. This would include cuts to ARPA–E.

What are the long-term costs of major cuts to Federal funding for energy science research like ARPA–E.

Dr. FURMAN. Thank you very much. I should start by saying that I do not have a substantial amount of expertise in evaluating ARPA–E in particular. My understanding, however, and I will get back to the Committee if I turn out to be incorrect, is that ARPA–E represents a fairly substantial fraction of Federal support for energy-related research and is a very important early stage funder for these types of technologies. A good deal is done in the private sector, but it is does not appear as if those private sector investments have yet yielded very promising outcomes.

And so, without putting specific numbers on it, which I think would be irresponsible of me, it does appear to be a fairly substantial long-term impact, unless this turns out to be an area in which private funds can rush in, in a measure that they have not in the past.

Senator UDALL. Great, thank you for that answer.

And, I do not have a final question, but Mr. Augustine, I just wanted to thank you for putting your emphasis on, even in hard times, investing in America COMPETES and all the various STEM fields. Really appreciate your effort there and your service on the Committee that then led to the legislation.

Mr. AUGUSTINE. Thank you.

The CHAIRMAN. Thank you, Senator Udall.

Chuck Vest has been a pretty good soldier, too, hasn't he?

Mr. AUGUSTINE. One of the best.

The CHAIRMAN. West Virginia, needless to say.

Senator Thune, South Dakota.

STATEMENT OF HON. JOHN THUNE, U.S. SENATOR FROM SOUTH DAKOTA

Senator THUNE. Thank you, Chairman. And thank you, the Ranking Member, too, for a good couple of years. And I, too, will really miss our Ranking Member, Senator Hutchison. It has been great working with her on so many different issues like transportation, although my thinking is that this may be premature, because I have a feeling in a lame duck we may be kind of busy around here.

[Laughter.}

Senator THUNE. So anyway, this could be perhaps our last hearing. So, I just wanted to say how much we appreciated working with both of you and, of course, with Senator Hutchison.

Let me ask, if I could, Dr. Wieman, a question about something you said in your prepared testimony. You stated that, and I quote, "There have been countless national, local and private programs aimed at improving STEM education, but there continues to be little discernible change in either student achievement or student interest in STEM."

So, my question is a fairly direct question. In this period of extreme stress to the Federal budget, do you believe the dollars that we are spending to improve STEM are being wasted?

Dr. WIEMAN. It is a sweeping statement to say they are being wasted. I think many of them are being well spent, but there are also a lot of them that could be spent much better. As I mentioned in my remarks, I think the way that we are funding K–12 STEM education through scholarships to potential teachers, the particular way I think that is being done, I think, is not having a particularly desirable effect.

Also, if you look at the evidence of results, there is a lot of money that goes to teacher professional development, where I think that is the evidence is it is not working very well, and there are some basic reasons it is not. Most of the teacher professional development programs end up focusing on improving the teacher's STEM content mastery, which is because that is where the most serious weaknesses up.

However, you are trying to take someone who went through 16 years of school, where their focus was on learning, and then say, "Well, they did not learn during school, so we are going to have some voluntary intermittent professional development activity to fix it." And meanwhile we are paying them full salaries.

It is not surprising that this is not a very good use of money. And, I think that money could be put to better use focusing on training teachers in the beginning in a much more rigorous way.

Senator THUNE. Anybody on the panel disagree with that?

Dr. WIEMAN. What?

Senator THUNE. I am just asking if anybody else on the panel has a different view or disagree with that, what is your view about any discernible progress with regard to student interest or student achievement as a result of STEM.

Mr. AUGUSTINE. Well, certainly if one looks at the standardized tests having given over the years, there has been very little improvement. There will be one area that will improve a little bit, one year and another and another. But, I think there is no real evidence that we have done much better. And, I doubt that there will be that sort of evidence until we get teachers that are qualified to teach in the core subject or have core degrees in the subject they are teaching.

Today, the chances are very high that a student will have a math or physical science teacher who has neither a degree nor a certificate in those fields.

If you will permit a personal experience, I took early retirement because I had always wanted to teach. I have a master's degree in aeronautical engineering with a lot of math. I tutored math in college. And, it turns out I am not qualified to teach eighth-grade math in any school in my state. Fortunately, the people at Princeton on the faculty there heard I was unemployed and invited me to join the faculty and teach in the engineering school, which I did.

The CHAIRMAN. You are a virtual John Nash.

[Laughter.]

The CHAIRMAN. Ignored by faculty.

Mr. AUGUSTINE. That would be an honor.

Senator THUNE. There was a report out yesterday that I was proud to see. It came out of *Bloomberg News,* that recent graduates from a South Dakota engineering college, the South Dakota School of Minds and Technology, are earning more than recent graduates from Harvard University.

And, aside from the personal pride in South Dakota that we have from that, I am wondering what that says, if anything, what that data point says about STEM. Are we reaching a point where it really does not matter whether you are receiving a STEM education at an elite university or a state university?

Mr. AUGUSTINE. Well, I will be glad to try to comment on that. I think that the market is recognizing the importance of STEM, and there has been a long perception that STEM degrees do not pay well. The truth is that STEM degrees on average pay better than most other professions requiring a comparable degree of education.

The difference is that trail of the distribution function that shows salary in many other fields is very high, whereas in engineering it tends to clip off. You tend to hear about the Warren Buffets and so on. But, on average, the STEM fields do pay well, particularly engineering. And, I think what you are seeing is that a good engineer from the University of South Dakota may well draw at least a better starting salary than the average graduate from Harvard.

Dr. LEE. Just from the perspective of Microsoft, we find great talent from every school, and we are always receptive to that. One slight extension I would make to Mr. Augustine's comments is that, in computing education specifically, we have continued to see, over the last five years of COMPETES, a very good increase in enrollments in undergraduate programs in computer science. But, that has not been reflected in high school level education in computing.

And so, as I look to the future, the incorporation of computing and computer science in our concept of STEM I think would create more opportunities and fill the pipeline.

Senator THUNE. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you.

Senator Cantwell.

STATEMENT OF HON. MARIA CANTWELL, U.S. SENATOR FROM WASHINGTON

Senator CANTWELL. Thank you, Mr. Chairman, and thank you for holding this hearing. And, I do not know if it is the last hearing we are going to have, but certainly want to add my thanks to Senator Hutchison for her leadership as the Ranking Member and her commitment to this Committee over her time in the Senate. I can think of many memorable moments in this Committee, particularly around aviation issues and slots, in which Senator Hutchison played a key role.

In particular, I remember one day we had a vote here when, I think, our colleague, Senator Hollings, was still Chair of the Committee, and the discussion went back and forth, and there was a lot of confusion about who was seconding and not seconding, and what the normal procedure was. It turned out to be a very interesting day, and we appreciated your leadership then, and certainly wish you well.

So, I have no idea whether this is the last hearing or not, but certainly do really appreciate your hard work and focus for America on many, many issues related to commerce, but particularly to aviation.

I wanted to turn—well, I do have a question, you know, about STEM for the panel in general, and that is just that, as I have looked at these STEM focuses in Washington State, whether it is the Delta High School in Richland, which is focused in particular from a lot of help because of the national laboratory that is there in Battelle, or I look at Vancouver IT Preparatory School, which has gotten a lot of help from the high tech industry there, or I look at Aviation High School, in Seattle, which has got a lot of help from Boeing, or what is now going to happen at Riverpoint Academy in Spokane, again a lot of help with the healthcare industry stepping up.

The question becomes, you know, a lot of these things have, you know, incubation or help and support from private sector entities that care a lot about establishing these programs, and they seem to be doing quite well in breaking down the barriers, but what do we do about scalability? Are we only going to have successful STEM programs where there are successful private sector partners? Or, if a neighborhood just does not happen to have that successful partner, how are we going to leverage that, you know, private sector commitment for doing STEM?

So, I do not know if anybody has any comments on that. Dr. Lee?

Dr. LEE. So, I would be happy to give some reactions. So, first of all, it is very important for Microsoft to invest in education locally. There are lots of reasons for that. If we look at the major universities in Washington State, they are producing computer science graduates at a rate that is below the number of openings we have annually at Microsoft. And, that is not just a workforce pipeline issue.

But, in fact, as we recruit, we are recruiting people who tend to have children who they would like to have local opportunities for education in similar fields. And so, it is also for us a community, and development, and recruiting priority.

And, as you pointed out, then the question is, there is only so much that we can do locally. How do we scale? And, how do we scale?

Senator CANTWELL. And, is not the number that something, like, we need 300,000 computer scientists on a national basis every year, and we are graduating like 73-or-some-thousand? We are not off by a little. We are off by a lot.

Dr. LEE. That is right. And so, I think I am heartened by the fact that, over the past 5 years of COMPETES, at least at the collegiate level, we are starting to gain some traction. We are starting to see some increase. I do worry about the pipeline running dry though at the K through 12 level.

So, things that we can do in the context of COMPETES or in other ways to increase interest, increase our effectiveness, to increase the number of teachers who are able to provide instruction and interest and inspiration, particularly at the K through 12 level, I think is a very important place to look.

Mr. WINN. If I may, Mr. Chairman, I would like to respond as well. We are expanding a STEM advanced placement program as one of our standard programs at the National Math and Science Initiative. We are now in 300 high schools in the United States.

And, I can say that the investment, particularly local investment of corporations and private industry, are alive and well. In fact, far exceed government-sponsored funding for implementing new and innovative advanced placement programs.

We are in the process now, since we have been over four years of instilling the programs and scaling them up. We started with about 60 schools in 2007 and 2008, and we are in 300.

And, we are just now seeing part of our replication program is to work on ways to sustain the program, because we believe that corporations have an incredibly important role, but more as a catalyst to get innovation started than to sustain programs in schools over long periods of time. And so, in the spirit of that, we have had corporations be very responsive to doing just that, and now we are in the process of working with state and local school districts and state legislators to help fund the continuation of those programs.

And, part of that process is demonstrating the remarkable improvement in advanced placement passing scores by all students, but particularly by underrepresented students, females and minority students.

Senator CANTWELL. Thank you. Thank you. Did you have something, Dr. Wieman, that you wanted to add?

Dr. WIEMAN. I would just add that you have touched on a very real problem. As Dr. Lee says and Dr. Winn reiterated, industries really like to invest locally, and what that means in some geographic sense, the rich get richer and the poor get poorer. And so that makes it a Federal problem, how to ensure those industry efforts do not result in wildly different educational opportunities in different regions. I think this is a very important problem that you need to think about.

Senator CANTWELL. Well, my time is almost up, but I think what Mr. Winn was saying is so, for example, if Dell was the big supporter of STEM in Texas that, you know, once you got one school district going, then you would go to the state legislature and others and say, "OK, now how do we replicate this?" Is that right?

Mr. WINN. Yes.

Senator CANTWELL. Is that what you were saying? OK.

Dr. WIEMAN. And, if I may——

Senator CANTWELL. So, the question is, how do we, you know, take Aviation High School and replicate that across a bunch of different jurisdictions, I guess?

The CHAIRMAN. This is the day of the Hutchison bonus. So, if you——

Senator CANTWELL. Oh, I have time? OK. All right. Well, I just wanted to point one more thing out. I came in right at the RPE debate, and I just wanted to point out, I am, you know, pretty sure that Bill Gates and the CEO of Cummings basically came up with, what they thought was, a private sector number for what they thought RPE should really be, right? You may have discussed that. But, to me, having those two individuals, you know, talk about what RPE investment levels should be and try and get people here to recognize that, I think is very important, that we try to achieve that level of investment. Thank you.

The CHAIRMAN. OK, thank you.

Senator Boozman from Arkansas.

**STATEMENT OF HON. JOHN BOOZMAN,
U.S. SENATOR FROM ARKANSAS**

Senator BOOZMAN. Thank you, Mr. Chairman. I do not have any questions, but I apologize for being late as this is such an important hearing. I, like everybody else, have 2 or 3 days to get 2 or 3 weeks' worth of stuff done here. I was able to listen to the testimony however, as I was in my meeting. So, I just want to thank you all for being here.

The discussion that we have had is so important as we go forward for our country. This has always been the bright spot in our country, being able to innovate. I know that we are committed to doing all we can to help, and we appreciate your comments.

I would also like to thank Senator Hutchison so much, for a number of different deals, in the sense of your leadership, your ability——

The CHAIRMAN. Did you say a century of leadership?

Senator BOOZMAN. Oh no.

[Laughter.]

The CHAIRMAN. That is good.

Senator BOOZMAN. Anyway your ability to have so much knowledge on the individual issues has been just a great example for us young folks in the sense of not having been here in the Senate very long. And also, for your kindness in making all of us new members to the Committee feel welcome. We appreciate it, and you will be very missed. Again, we just appreciate all you have done for this Committee through the years.

Senator HUTCHISON. Thank you very much. I hope we have another hearing so I can hear all of this again.

[Laughter.]

Senator HUTCHISON. Except the poor witnesses have had to endure it.

The CHAIRMAN. Let me just ask another question. If somebody else wants to ask, fine. We have wandered here a bit, have we not? And, nobody is challenging America COMPETES. Nobody is challenging the need for Federal help on this. We accept two stipulations.

One, that there is probably going to be a cut in this program. And, the question is, how much will it hurt? Which brings to mind two thoughts, one is that it will hurt, and the other is what Norm Augustine said, and that is when Northrop Grumman had to cut back by 50 percent or 45 percent, whatever it was, they became better. Now, I am not sure that corporations work the same way as government, or rather government works the same way was corporations, but it is an interesting thought.

The second is what you said, Dr. Lee, and that is, you just threw the comment in, and it was very important to me, that we are finding good people in all kinds of places.

So, my overall question is, we recognize that America COMPETES is not out to gratify on the short-term basis. It just cannot do it. It has been around for quite awhile, and it went through some National Science—I am sure there was some bureaucratic fulminations about it there.

But, it did change its philosophy. It did reach out more. The world has changed dramatically. And, it has all changed in the direction of what it is that America COMPETES, in fact, is trying to do, and I do not care if it is biology, petroleum, or engineering. I mean, it is that young people are infinitely curious. All you have to do is walk into, you know, an elementary school lab and look at the intensity of these people. You cannot even see their noses because, you know, the earpieces are so big, and they are focused on their computer. I mean, it is absolutely inspirational.

Then you get through the latter part of K through 12, and that is called the teenage years, and concentrating on anything gets to be more difficult. Then you get into the college years, and that is when things are meant to get serious, except when people say, “Well, some people go to college just to grow up.” Well, those are not meant to be the people we are focusing on. We are meant to be focusing on the people who do not go to college to grow up, but to grow really, really good at needed STEM subjects and other areas within our entirely new economy.

So, I want somebody just to make the case for America COMPETES. One of the five of you is charged with doing that. Tell me what it is important, fully funded, three quarters funded, or whatever.

Mr. AUGUSTINE. Thank you for the opportunity to take a crack at that. Much of what America does and is able to do for its citizens requires financial resources by those citizens and by the Government. And, our economy today is, to a very large degree, underpinned by advancements in science and engineering and by our ability to compete for jobs.

Today, unlike the past, when American citizens competed with people across town for their jobs, today they compete with people around the world for their jobs. The people around the world are now much more highly educated, they are very hungry, and very anxious to get good jobs.

If Americans cannot compete for those jobs, and we are becoming less and less competitive as every day passes, we will not have the income to pay the taxes to provide for national security or healthcare, we will not have the money to provide for education.

And, if we are to fix this, there are two things we have to do more than anything else. One is fix K through 12, and in addition to that, now I have to add to attend to our higher education system. And, the second is to greatly invest into our knowledge.

America cannot compete based on the cost of our labor. The fact that we have a lot of capital, that capital invests abroad now. So, America COMPETES Act, that is what it is about, is creating jobs for America for the kind of reasons I have stated.

Mr. CHAIRMAN. So, it is kind of a last course, last stand. I do not mean to put that pessimistically, but I will just say that. It is kind of a last stand for, are we going to take world competition seriously, or are we not?

I happen to agree, and I wish Kay Bailey Hutchison were not in the room right now. I happen to agree with you about paying the coaches and the symbolism therein, the emphasis on athletics, the domination of ESPN over virtually everything that happens in the private time of the American citizen and so many universities, and their grasp for that dollar, and what they will do to get that dollar, and what suffers because of their willingness to grasp for that dollar. I happen to feel very strongly about that. There is not much I can do about that. So, I have got to live with what remains.

I would stipulate that the average American, who you earlier referred to as perceived to be a geek, that there are a lot of them, and that they are very proud of what they can do. In fact, it opens up to them, and I am thinking now particularly about rural areas, you know, less about Austin and more about something that begins with "A" in West—Aracoma, West Virginia, that—I mean, I will just give the example.

A number of years ago, 12 years ago, 13 years ago, I met a girl from McDowell County, which is one of the four poorest counties in the United States of America, year after year, after year, after year, after year, to the extent that it has been taken over by a teachers union, which happens to be doing it without the idea of unionizing, but with the idea of improving education in this McDowell County, out of coal, out of jobs, out of hope, strung out by drugs, but still there are people there. They have taken it over. They want to make it work.

That instinct still lives in this country. So, we are going to have to figure out a way. I spent a lot of time sitting with math and other STEM teachers, hours with them, including a couple women who used to be coal miners, but they are really tough math teachers today, and really good, and proud of it.

So, you cannot tell me that American ingenuity is not tapped into, that there is not something that is appealing in what is going on in this country so manifestly and clearly, and that is high technology, and that people want to tap into that.

Now, I understand there are rural areas there are people that think they cannot tap into it because God has it in that they are just not going to be able to tap into it because they are poor, and they are going to stay poor, and you know, there parents are not pushing them, and all that kind of thing. I understand sociology.

But, most of America does not fit into that category and is made up of people who have every reason to be turned on by what Microsoft is doing, what you have been working on, Norman, and you have been terrific, Carl, at what you have said today and your understanding of all of this, and as have you Dr. Furman, and therefore, I should say you also, Mr. Winn, turned on by this opportunity.

And, I am confounded that we cannot do it. We put up an America COMPETES. America COMPETES helps substantially, but not enough. Well, not enough is not a reason to quit something.

I mean, you know, it is like hacking in cyber security. You put up a wall, then somebody else puts up a higher wall to get in, and then you put up a higher wall. I mean, that is just part of life, and that is going to go on in anything that has to do with technology.

So, for the life of me, I cannot figure out why it is that more Americans cannot get turned on by STEM. I have—Sharon and I, I should say would be I think rather more fair, for our children, two of them are involved in high technology. I had not a wit to do with it, nor did my wife. They just—they went to good schools. They—one of them was a teacher of special ed in Harlem for 4 years, and then sort of graduated on into other things. Another is teaching at Johns Hopkins. And they are just—you know, sure they got a better start because they had a good education.

But, it defies my sense of hope for America that there are not more kids doing this. And, we have a program to help on it, where people in states that care about it, most states have councils on science and technology, some probably better than others. So, maybe we are waiting for a recession to end. Maybe we are waiting for a nation to gain confidence, like we are waiting for industry to gain confidence, so that the $3 trillion that they are sitting on, that they will begin to spend, because they have confidence in something called the future.

Now, is there any parallel or any sense in anything that I am saying? Please, any of you, and then we will be finished with the hearing.

Dr. WIEMAN. Just make a quick comment. These attitudes people have about science is something my own research group has done a lot of work on. We have primarily looked at students at the introductory college level, but we see that the formal schooling system and the formal classes, like an introductory science course at a college or university, actually shifts the students' attitudes against science, so they see science as less useful and less relevant to their lives than they did before they ever started that class.

So, that has told us some things about how these classes are being taught that is actually hurting rather than helping.

The CHAIRMAN. Are we talking K through 12?

Dr. WIEMAN. No, Our data is from students at the introductory college level.

The CHAIRMAN. Introductory college, OK.

Dr. WIEMAN. I am quite confident that if we dig down and understand why this is happening, we will very likely see that it is happening even more so at the K–12 level. This is just another one of these advances in research and learning we we suddenly realize, "My God, that is what is happening," and then you go and figure out how to fix it, which we have done. But, there is a lot in the formal school system that I think is affecting those attitudes about science and engineering in negative ways.

Dr. LEE. I have a comment. I was really impressed with your statement, and I think underlying that is something very important.

A colleague once told me, in tongue in cheek, that a young person opting to go to a good college to study science or engineering is the modern day equivalent of joining a monastery. And, it is a joke, but it is a joke that is getting at the basic societal concept that that is a strange choice. But, in that——

The CHAIRMAN. Why is that a strange choice, Dr. Lee?

Dr. LEE. It should not be.

The CHAIRMAN. The examples are all over television, the newspapers, they are spoken about all the time, the example is exactly the opposite.

Dr. LEE. I agree completely. And so, I think what is exposed by this is, as adults, we see that this is important for the future, for our competitiveness, for jobs. But, young people who make these choices, also are making choices to go for some idealism, to really be a part of a community that is just trying to express their curiosities and their creativity, and along the way, make a difference in the world.

And so, to the extent that, as leaders and as legislators we are, on the one hand, talking about the practicalities, practicalities about finance, about competitiveness, about innovation, and jobs, but not forgetting about this basic idealism in young people and making sure that we express ourselves in a way that touches that idealism, if we forget that, we will risk coming off making all of the wonderful things we do in science and technology look too mundane. Instead, we really need to inspire young people.

The CHAIRMAN. To wit, and then I will quit, the applications at the Peace Corps, which I was a part of a long time ago, are higher and at higher levels of aptitude than they have ever been in its long history.

Dr. LEE. Perfect example.

The CHAIRMAN. The applications for people who want to join the CIA and to do covert or non-covert operations, but dealing with algorithms and all kinds of things, is higher than it has ever been, and the quality of the applications is the highest than it has ever been. That is the "I want to be a part of the future. I want to be a part of the world. I want to make the world better."

So, the question is, how do you change over to what we have been talking about today? And, that we will have to leave unfinished business, but with Kay Bailey Hutchison, such as time as she still has, but from a distance anyway afterwards, and myself, and all of us, determined to make it work.

I thank you all very much, and this hearing is adjourned.

Senator HUTCHISON. Thank you.

[Whereupon, at 4:23 p.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

The National Oceanic and Atmospheric Administration (NOAA) is proud to support the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act. NOAA thanks Members of the Committee for giving the agency a prominent role in this historic effort to enhance American competitiveness.

As part of America COMPETES, NOAA was charged with implementing programs and activities "to advance ocean, coastal, Great Lakes, and atmospheric research and development, including potentially transformational research." As a mission-driven, scientific agency NOAA has to balance incremental scientific advancements to operations with transformational research. Transformational research and development is an investment that often carries a level of uncertainty, but has the potential to positively affect society in substantial ways that increase earth system knowledge and produce technological advances that fuel economic opportunity. NOAA's transformational research inspires students and researchers alike to push the limits of knowledge.

As an example, consider the High Resolution Rapid Refresh (HRRR) weather model. This new experimental model, under development by NOAA's research community in collaboration with our operational weather forecasters, is designed to more accurately predict high impact weather events. This new generation of ultra-high resolution (3 km) weather models predicted the derecho event on June 29, 2012 in excellent detail ten hours in advance of its arrival to Washington, DC. Models such as this have the potential to radically transform our ability to forecast events such as the derecho and therefore greatly enhance NOAA's ability to conduct its mission to save and protect lives and property. As computing capability continues to improve, HRRR could be transferred from research to operations and applications. NOAA is also active in moving hydrodynamic coastal models from research to operations by developing and implementing coastal nowcast/forecast systems for several major U.S. Ports. These ports systems are taking advantage of NOAA's High Performance Computing and Communications facility for safe and efficient management and use of our coastal resources.

In addition to model improvements, NOAA has transformed its ability to gather observations over the last decade. In the climate and oceans arena, drifting probes that can be deployed throughout the ocean—called Argo floats—have revolutionized our ability to observe and record the physical conditions of the global ocean. In the past, scientists studying the interplay between ocean and atmosphere used CTD (conductivity/temperature/depth) recorders deployed from research vessels to get temperature and salinity profiles. These profiles formed the basis of much of our basic understanding of the ocean. Limited by our ability to physically sample wide areas of the ocean and the inherent costs and limitations associated with ship time, there were large data gaps such as the Southern Ocean, and data were mostly limited to the upper 750 meters of the ocean. Argo floats are now routinely used to continuously collect data at depths of up to 2,000 meters and transmit the data to scientists on shore via satellite. The Argo float network and other global array systems have allowed for the collection of temperature and salinity profiles throughout the global ocean. They have vastly improved our ability to estimate and forecast sea level rise, and play a key role in improving seasonal climate forecasts and providing new insight into hurricane activity. The next-generation of Argo, deep-Argo floats, is under development and will extend our ability to comprehensively observe the ocean far beyond the existing 2,000 meter depth to as many as 6,000 meters.

While the development of the HRRR model and the Argo float network are examples of transformational research, use-inspired incremental, or evolutionary, research also has the ability to shift paradigms over longer time scales. An example of this is the shift from traditional species-by-species fisheries management to ecosystem-based management. The traditional management strategy for fisheries and other living resources has been to focus on one species of fish and shellfish in isolation. For example, if there were a decline in the number of a certain type of fish in the Gulf of Mexico, the relevant Council might recommend and NOAA might decide to decrease the number of that species that could be taken. That approach does not take into account other elements such as interactions with other species and the effects of pollution and other stresses on habitat and water quality. To more effectively assess the health of any given fishery and to determine the best way to sustain it requires a holistic understanding of the ecosystem. Ecosystem approaches are transforming our ability to manage fisheries by considering the cumulative effects from various sources, and the balance of conflicting uses.

The power of America COMPETES speaks not only to our Nation's strong scientific expertise but it also furthers NOAA's strong education ethic. The Act complements existing education mandates found in the authorizing legislation of specific NOAA programs, and provided NOAA with a broad, agency-wide authority for education. To provide a clear and coordinated path forward, the NOAA Education Strategic Plan (*http://www.education.noaa.gov/plan*) was developed, which outlines our 20-year education vision, goals, and strategies needed to support the agency's mission. The NOAA Education Strategic Plan, the subsequent Implementation Plan, and most recently, the Monitoring and Evaluation framework have resulted in increased internal collaboration and leveraging of resources, not only among the agency's education programs but also with external partners. We are proud to report a few illustrative examples of the progress NOAA has been able to make in response to the Act this year.

In 2012, NOAA is projected to support 513 students through competitive internships, fellowships, and scholarships who have been awarded NOAA mission-related Science, Technology, Engineering and Mathematics (STEM) post-secondary degrees, out of which 57 are from underrepresented communities. For America to be competitive in the global marketplace, we need bright, creative minds. Our job is to see that we give as many young people as possible many opportunities to learn, stretch in new directions, develop critical thinking, ingenuity, and scientific expertise.

In 2012 alone, we project 49.7 million people will visit informal learning institutions with a NOAA-funded exhibit or program that integrates NOAA's unique science products and services. NOAA partners with informal learning institutions such as museums, zoos, and aquariums to make NOAA sciences, data, and other information widely available to the American public through interactive STEM exhibits and programs. NOAA's products and services are essential to explaining current, real-world STEM issues such as climate change, oil spills, extreme weather and weather safety, appropriate management of coastal environments, and overfishing.

In 2012, NOAA will serve an estimated 41,000 educators through professional development programs and estimates nearly 7 million visits to NOAA education websites. Such programs and resources aim to enhance understanding and use of ocean, coastal, Great Lakes, weather, and climate environmental information with the goal to promote stewardship and increase informed decisionmaking.

Through scientific rigor, cutting-edge research, and integrated STEM education NOAA is committed to developing and attracting the next generation of scientists who will drive the scientific and technological innovation our country needs to stimulate the economy and create jobs. Through the authority granted by the America COMPETES Act, we offer the American people access to the unique and significant resources of a mission-driven, scientific agency. Coupled with NOAA's investment in education ($53.8 million in FY 2011), we effectively leverage NOAA's significant scientific expertise, laboratories, data, ships and aircraft, and places of special significance to the Nation (such as our National Marine Sanctuaries and National Estuarine Research Reserves) to offer high quality, mission-relevant, formal, and informal education opportunities.

Educating our students in the STEM disciplines will help them understand their world and provide useful scientific advances to society. In turn, that prepares them with the critical thinking skills they need to get better jobs with better pay for a brighter future. We at NOAA will continue our efforts to attract, promote, and engage more talented scientists of all ages—scientists who will help keep America on course to win the future and help us develop the next transformational scientific break-through.

Thank you again for the opportunity to share our enthusiasm for the strong support that you have shown in propelling our Nation's economy and competitiveness forward. NOAA is proud and pleased to play a role in this effort—both in developing the next transformational scientific tools and in preparing the next generation of scientists to make those discoveries for tomorrow.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO NORMAN R. AUGUSTINE

Federal funding for physical science and engineering basic research increased at a faster rate in the past five years than in the preceding decade, but applied research funding has declined with inflation.

Question 1. What might be the competitive implications of increasing the funding for basic research as compared to flat or even declining funding for applied research?

Answer. As your question implies, there needs to be a balance between funding for basic and applied research. My own view is that basic research was so severely underfunded, particularly in the physical sciences, engineering and mathematics, that the steps of the past few years have been in the direction of restoring balance rather than disturbing it. Unfortunately, at least as one looks towards sustainability, much of the increase in basic research was funded by the stimulus package and has therefore been consumed.

Question 2. What innovative, funding-neutral policies should the Federal government pursue that it is not currently?

Answer. This is a very difficult question because, unfortunately, the fundamental problem is one of underinvestment in both basic and applied research. Most revenue-neutral changes tend to have an impact at the margins; however, constructive actions would include placing greater emphasis on high payoff (perhaps higher risk) efforts; greatly reducing administrative costs associated with reporting requirements; cutting the time-demand associated with writing grant requests; and eliminating earmarking.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. BILL NELSON TO NORMAN R. AUGUSTINE

Question. Dr. Lee noted that Microsoft invests more than $9 billion a year towards research and development. However, right now, companies in the U.S. are sitting on around $1.7 trillion in cash instead of investing it in new technology, and you noted that U.S. corporations spend over twice as much on litigation as on basic research. What can the government do to encourage companies to invest more in research and technology here in the U.S.?

Answer. Frankly, were I an active CEO at this point in time I, too, would be "sitting on" our firm's cash. The reason for this is that CEO's bear a legal fiduciary responsibility to their shareholders and the uncertainty in the market affecting everything from taxes to interest rates to inflation are simply too great to warrant major investment under today's conditions.

But there are constructive steps the government could take with regard to the permanence and magnitude of the R&D tax credit; the repatriation of foreign earnings; and the clarity of tax policy.

A principal problem in encouraging long-term investments (in such areas as R&D) is the "results now" psychology of Wall Street that encourages "financial engineering" rather than productive pursuits. This could be changed overnight by adopting a new capital gains tax policy whereunder profits from investments held one day would be taxed at ninety-nine percent and profits from investments held over ten years would be taxed at one percent. . .with some schedule between the two that produced whatever revenues were sought.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. AMY KLOBUCHAR TO NORMAN R. AUGUSTINE

Question 1. You discuss effective teaching models in your testimony when it comes to both STEM courses and the fact that U.S. youth seem disinterested in the study of science and engineering despite a fascination with the products of these fields. How do we effectively motivate students to enter and stay in STEM fields? What impact does the Federal government have in inspiring students through events like the Curiosity landing on Mars last month? What are the keys to inspiring students to pursue STEM education goals?

Answer. In my generation a large fraction of those who pursued careers in various branches of science and engineering were inspired to do so by the Apollo Program. I believe that the same effect could be produced today by a (sustained) Apollo-like program in the field of energy.

But it is also clear that the most important single step government could take is to ensure that every classroom has a teacher with a degree specifically in the field wherein they are teaching. This is far from the case today, particularly in math and science. This objective could be accomplished by fully implementing the proposals related to this subject that were contained in the Gathering Storm report.

Question 2. I worked to include university commercialization reports in the COMPETES Reauthorization Act. I understand measuring the long-term economic impact of the COMPETES Act programs is inherently difficult—it is often difficult to trace any specific breakthrough or innovation all the way back to a specific research grant, additionally, these projects take time. What is the best way to measure the success of these programs? What indicators should we look to? For example, is there a way to estimate how many jobs are created by a program or by the Act?

Answer. I, of course, am an engineer and not an economist. However, I agree both with your emphasis on measuring outcomes and with the difficulty of doing so, particularly when addressing research efforts. I feel certain that the individuals working on quantum mechanics and fundamental materials behavior many years ago did not have iPads and iPhones in mind!

There have been a number of generally successful efforts to measure the impact of prior advancements in research and engineering on the growth in GDP. My own correlations suggest that each percentage point growth in GDP is accompanied by at least a 0.6 percentage point growth in employment. It is unfortunately difficult to isolate cause and effect; however, my own experience suggests that there is an ample amount of the former present. I do believe that such quantitative analyses are possible and meaningful—but are limited as a management tool because of the long time-lags that exist.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO CARL E. WEIMAN

Question. What innovative, funding-neutral policies should the Federal Government pursue that it is not currently?

Answer.

1. Making transparency in STEM teaching methods a requirement for Federal research grant eligibility.

Current Federal programs are providing incentives to preserve bad STEM teaching at both the college and K–12 levels. At the college level, far more effective methods of teaching have been repeatedly demonstrated, but faculty and institutions ignore those results and continue to use ineffective lectures as they focus solely on research (see recent NRC study). The large amount of Federal money for research has driven that single-minded focus. What is needed is to attach some modest level of educational accountability to the large amount of Federal support for science research ($30 B/yr).

The Federal Government should establish a policy that would require transparency in the teaching practices used by STEM faculty members and academic departments, in order for them to be eligible to receive Federal research funds. This could be done by requiring each STEM department to report in a standard format on the teaching practices in use in their undergraduate courses, as well as overall student outcomes, such as number of majors and graduation rates for majors, and completion rates in first year courses. In my university work, I developed a survey that adequately captures the extent to which a course is being taught with new, demonstrably more effective, teaching methods, or less effective traditional lectures. This survey only takes about 5 minutes to fill out for each course offered, so the cost of collecting such data would be minimal. NSF should be charged to develop the instrument and collect the data on behalf of all the agencies, since the NSF has the most expertise and are best positioned to institute such a system rapidly.

Universities would be required to provide this data for every STEM department that wanted to be eligible to receive Federal research funds. This departmental level data would then be published so that prospective STEM students could compare departments and institutions as to which were using more effective teaching methods and which had the best student outcomes, and make their decisions about where to enroll accordingly. I am confident that this would be sufficient to bring about rapid improvement in the teaching practices in use at the university level. It will provide accountability and transparency at the level where teaching practices are determined and can be changed, namely the level of the academic department. It would be unnecessary for the Federal Government to attach any requirements to educational practices and outcomes, other than transparency.

This reporting of teaching practices will be opposed by the leading research universities because they have achieved their elite status by focusing entirely on research prominence. This will now subject them to a different standard—one where they likely will not fare nearly as well, and it will force their faculty and administration to shift their priorities slightly if they are to look respectable.

2. Shift current Federal STEM teacher preparation funds and STEM teacher professional development funds to create a program to drive the overhaul of teacher preparation programs.

To improve STEM teaching at the K–12 level will cost money to change the teacher preparation programs, but this could be achieved in a funding neutral manner by putting all the money that is currently going for STEM teacher training and professional development for in-service teachers to this much better use. This would amount to several hundred million dollars per year. As I discussed in my written testimony, the evidence shows that these funds are currently accomplishing very little and there are basic structural reasons why such programs can never be effective. Current teacher training programs focus largely on admitting and graduating as many students as possible to maximize tuition revenue, with very little attention paid to the STEM competence of those teachers or the training needed to be effective STEM teachers. Much better use of those funds would be to support Federal programs that provide incentives to institutions to create rigorous new STEM teacher training programs and recruit highly qualified students to complete those programs. There should be rigorous criteria established for programs to be eligible for these Federal funds, criteria that will require major changes in most every teacher training program. These criteria should focus on ensuring every teacher candidate achieves both high levels of STEM content mastery and detailed training and practice in effective STEM teaching methods that are aligned with the latest research. The programs should require joint involvement of both the Schools of Education and the STEM academic departments at the institution. It would be sensible to consider also supporting this program with some of the money that is currently going to support programs that fund various informal science activities that are designed to inspire students. As I discuss in my written testimony, there is little evidence that these programs accomplish the goal of getting more kids to pursue STEM careers, and good reason to believe they never can, for the reasons I gave in response to Senator Klobuchar's question. Whatever inspiration these programs may create, it will not survive the uninspiring teaching of science that takes place in school and which dominates students' career decisions. So working to improve the teachers and help them build inspiration into the science they are teaching every day is the only way to achieve large gains.

3. Changes in the organizational structure of the Department of Education

Currently the U.S. Federal Government is badly organized for improving STEM education. Although done by many different agencies, it is always the third, fourth, or fifth priority of that agency and so never attracts the level of funding and quality of people and authority that is necessary to make a real difference. Historically the Department of Education has had little responsibility for STEM education, and as a result there is no place in the current organizational structure for STEM education and *very* little STEM competence in the department. The NSF has lots of STEM competence, but is fundamentally a research agency, and so is well suited to carry out critically important research on improving STEM education, but it is not well suited to drive large-scale change in educational practices across the country. That requires more extensive connections with States and local districts, like the Department of Education has. However, if the Department is ever going to be able to play a serious role in STEM education, it needs to create a new position with significant policy and budgetary authority and fill that position with a person who has solid STEM education expertise.

4. Fully funding the cost of Federal science and engineering research and stopping the increase in the reporting and compliance burden associated with Federal research.

Current policies unknowingly serve to drive up indirect costs and transfer those costs to undergraduate tuitions, seriously impacting college affordability. The typical undergraduate at a large public research university now pays about $5,500 per year of tuition to support research, with much of that total going to subsidize federally supported research. This has come about because of a variety of policies that have increased the indirect costs associated with federally supported research at academic institutions while also reducing the reimbursement for those costs. Because the amount of Federal research funding and associated prestige is all-important to a university, university administrators have quietly covered these unreimbursed costs by raising tuition rather than turning down Federal grants. Some university administrators have told me in private that it would be professional suicide for them to either admit to this policy or to oppose it. The extent of the problem can be seen in the NSF tabulation of the amount of institutional funds that each public university spends on research. This now averages $160 M/yr for a top 20 public university, up from approximately zero dollars 25 years ago. These institutions have no source of revenue *other than tuition* that has increased by nearly this amount over this time period, so most of this $160 M/yr can only be coming from tuition. Further analysis shows that much of it goes to subsidize Federal research by paying for the unreimbursed costs. While this has short-term benefits for the Federal research enterprise, it cannot be good for the long-term interests of the Nation. To illustrate how these costs arise, I will give one specific example, the NIH graduate fellowships. Tthe Federal Government, after careful auditing and negotiation, has concluded that there are indirect costs associated with having a graduate research assistant that amount to about 60 percent of their salary at a typical institution. These costs arise from the need to process their pay, taxes, etc, and the cost of providing them with office space, desks, labs, electricity and water, etc. However, the NIH only pays 8 percent indirect cost on all of its many fellowships, who all work as research assistants their respective universities. So if an institution has a student who receives and NIH fellowship, the institution has to find some other source of funds to cover those indirect costs amounting to 52 percent of their salary.

Changing this system will involve shifting costs from student tuition to the Federal Government, and so if the funds for research remain unchanged, will involve reducing the amount of research that is produced by a modest amount. However, I do not think that anyone would support a Federal policy of having student tuition being used to unknowingly subsidize Federal research, if they actually realized that is what is happening.

Because this issue involves billions of dollars a year and is so entrenched in the system of research funding, I would recommend dealing with it in stages. The NSF established policies and carried out much, although not all, of the first two stages below over a period of time, demonstrating that it can be done. Applying similar policies to the other agencies, particularly the NIH, which has the most research funding and the most programs that pay reduced indirect costs, is a necessary next step. As research universities have already demonstrated that they are willing to use surreptitiously tuition revenue to boost research productivity and prominence, the implementation of the stages listed below should be linked in some way to commitments to some combination of tuition reduction, increased student aid, or other appropriate enhancements of undergraduate education.

Stage 1—Preventing further growth in the number of programs that pay indirect costs that are "below negotiated rate". There should be a much higher barrier to agencies paying less than negotiated rate, for example, any such rates must be approved at a high OMB level. Similar restrictions should apply to programs wishing to use cost-sharing as part of the proposal selection criteria. So called "voluntary cost-sharing" is not at all voluntary when it impacts whether the proposal does or does not get funded.

Stage 2—Establish a schedule for gradually rolling back both the current "below negotiated rate" policies for specific programs, and the consideration of institutional cost sharing in proposal decisions. Some of these may be congressionally mandated. I think that may be the case for the 8 percent overhead paid on the NIH fellowships. However, if congress was made aware that for every dollar of Federal money that goes for an NIH fellowship, 50 cents from undergraduate tuition goes to support that fellowship, they may well be willing to reexamine that issue. This payment of the negotiated overhead rate and elimination of institutional cost-sharing will involve some modest reduction in the amount of research that gets supported. However, to put that in perspective, the amount of student tuition that currently goes to support research at the average large public research university is just about the same amount as the average annual debt incurred by every student at that university.

Stage 3—While the first two steps would reduce the problem of student tuition subsidizing Federal research it will never eliminate it as long as the artificial 26 percent cap on federally reimbursed facilities and administration costs remains in place. With that cap in place, agencies, congress, auditors, and OMB, will continue considering new requirements and regulations without carrying out a reasonable cost-benefit analysis. This situation has led to dozens of requirements and regulations being added over the years that didn't cost the government money because of the cap, but have very real costs to the universities. The universities complain, but they can never admit what the real cost is, because they have put themselves in the position that they cannot admit that they are subsidizing Federal research with tuition money. So we currently have a system where new indirect costs keep getting added by government policies, but they are paid through secret increases in tuition, so no one complains. Only if you eliminate the 26 percent cap so the government is paying the actual cost of research will there be transparency and an accurate cost-benefit analysis to any proposed new regulations or reporting requirements.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO CARL E. WIEMAN

Question 1. Dr. Wieman, your testimony suggests that in order to substantially enhance STEM education in the U.S., we need K–12 educators who have both a mastery of a science or engineering discipline *and* are well versed in the latest research regarding the learning process. How can we develop or attract educators to our K–12 classrooms that have such specialized knowledge and experience in both engineering AND education? Would it be more worth-while to invest in training experienced scientists and engineers to become teachers, or to invest in developing science and engineering skills in experienced educators?

Answer. This is a very important question. At the college level the data is pretty clear. It takes far less time for a scientist or engineer to learn to become a highly effective teacher than it takes to learn to become a scientist or engineer. The ratio is roughly a few hundred hours versus 10,000 hours.

The answer is less clear for the K–12 level, first because there are more factors involved in teaching effectively. The teacher has to learn to handle discipline issues, special needs students, classroom management, meeting state and district content standards, etc. that are not present at the college level. My speculation, based on the college results and the poor results from professional development of existing teachers, is that it would be more cost effective to train existing scientist and engineers to be effective teachers, but it will require much more than the few hundred hours of training and practice required for the college level. That speculation is strengthened by the results from teacher professional development, attempting to develop science and engineering skills in experienced teachers. Those results have been so dismal that almost anything else would be better.

However, it is unlikely that there could ever be sufficient scientists and engineers interested in going into teaching to meet the demand via this route. So I believe that the best approach would be to have programs to recruit and properly train a select group of experienced scientists and engineers to become teachers, and to develop the pre-service teacher training programs so that their graduates have the necessary STEM content mastery to be effective teachers. All of the evidence would imply that both of these approaches, training scientists and engineers to become teachers, and better training of pre-service teachers, will be more cost-effective than trying to retrain existing teachers so that they have high level STEM content mastery.

Question 2. Dr. Wieman, in your testimony you note that current practices incentivize universities to prioritize research over teaching, and you suggest as a partial remedy that Federal science and technology research grants should more closely tied to educational outcomes. What specific measurements would tell us which universities are best educating their students in the STEM fields?

Answer. I have spent a lot of time considering this issue. The situation is greatly complicated by the selection effects that make the student cohort at each institution unique. So the kind of measurements used with K–12 schools, which already have serious limitations in that context, are meaningless at the higher education level. Skipping a full discussion of all the complications here, I will just give my conclusions as to most useful and practical measurements to make.

Data should be collected on a combination of basic student outcomes and teaching practices used; all collected and reported at the level of the individual academic department. The most meaningful student outcome measures would be (1) number of student majors, (2) number of graduating majors, and (3) student completion rates for first year courses. It would be useful to have this data broken down by different under-represented minority groups, but care would be required in doing that in such a way it would not violate privacy laws when numbers are small. Departments typically collect all this student outcome data anyway, and they are already reporting much of it through the IES website, so collecting and providing all the data would be negligible.

In terms of teaching practices, the data that should be collected are what methods of teaching are being used in the undergraduate courses. How much of the class time is traditional lecture with the instructor presenting new material by talking while the students listen, and how much of the time has students and instructor involved in several teaching methods that have consistently been shown to achieve better learning and high student success rates compared to lectures. (The recent NRC study on Discipline-Based Education Research in Science and Engineering provides a good review of this research and which teaching practices are more effective.) This could be done by requiring each STEM department to report in a standard format on the teaching practices in use in their undergraduate courses. In my university work, I developed a survey that adequately characterizes how a course is being taught to allow distinctions as to the quality of teaching practices that were used. This survey and only takes about 5 minutes to fill out for each regular undergraduate course that is offered. For a large department, that is only 15–25 per year, so the amount of time and hence cost that an academic department would need to collect all the required data is rather minor, and departments seriously paying attention to undergraduate education should already be collecting much of this information themselves.

This data should be collected and published by the Federal Government to thereby provide transparency on teaching practices and student outcomes for each academic department that receives Federal research funding. I would strongly recommend against using the data in any decisions on research funding. The requirement would thus be one of transparency but not direct Federal accountability. I believe that would be the most effective way to accomplish the desired purpose, and it would be far easier to implement. Prospective STEM students could compare departments and institutions as to which were using more effective teaching methods and which had the best student outcomes, and make their decisions about where to enroll accordingly. I am confident that this market pressure would be sufficient to bring about rapid improvement in the teaching practices in use at the university level. This will have the further benefit that it will bring transparency and resulting accountability at the level where teaching practices are determined and can be changed, namely the level of the academic department.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. AMY KLOBUCHAR TO CARL E. WEIMAN

Question 1. You discuss effective teaching models in your testimony when it comes to both STEM courses and the fact that U.S. youth seem disinterested in the study of science and engineering despite a fascination with the products of these fields. How do we effectively motivate students to enter and stay in STEM fields? What impact does the Federal Government have in inspiring students through events like the Curiosity landing on Mars last month? What are the keys to inspiring students to pursue STEM education goals?

Answer. Any time that society gives recognition to science activities and successes it helps attract students into STEM. However, in themselves, events like the Curiosity landing have little long term effect. The problem is that students may get excited by missions to Mars, or Hubble pictures, or science fair projects, but then the science they see in school is totally different and quite uninspiring, and the "school science" is what determines the long term career path for most students. That is necessarily the result of school being their dominant exposure and hence defining experience as to what STEM is. This is true even into college, where many students switch out of STEM, because of poor teaching and boring curriculum. It is worse at lower grades where many of the teachers have little understanding or appreciation of science and present it as an exercise in rote memorization.

Ultimately, if we are to have more students enter and stay in STEM fields it will require teachers at all levels who can make science and engineering interesting and meaningful, and show students how these subjects are not just memorization of lots of facts and words, but rather creative intellectual processes that can solve problems that are meaningful and interesting to the students. Without that, events like NASAs latest triumph will make little difference, unfortunately. With that, those NASA triumphs will be seen as an extension and goal of what they are learning in school and will further inspire them to pursue STEM.

Question 2. I worked to include university commercialization reports in the COMPETES Reauthorization Act. I understand measuring the long-term economic impact of the COMPETES Act programs is inherently difficult—it is often difficult to trace any specific breakthrough or innovation all the way back to a specific research grant, additionally, these projects take time. What is the best way to measure the success of these programs? What indicators should we look to? For example, is there a way to estimate how many jobs are created by a program or by the Act?

Answer. I must defer to the economists who study such things for this question. I do not feel qualified to offer an answer.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO JEFFREY L. FURMAN, PH.D.

Federal funding for physical science and engineering basic research increased at a faster rate in the past five years than in the preceding decade, but applied research funding has declined with inflation.

Question 1. What might be the competitive implications of increasing the funding for basic research as compared to flat or even declining funding for applied research?

Answer. This is an excellent question to which, I believe, academic research has not yet supplied a fully satisfactory answer. The U.S has experienced a number of episodes in which basic research programs received substantial infusions of funding, including aerospace research (in response to the Soviet space program) in the late 1950s and the Apollo Program in the 1960s, the War on Cancer during the Nixon Administration, the doubling of NIH funding between 1998 and 2003, and the increase in research funding in the 2009 ARRA.

While such funding boosts are often a boon for short-term science and have been effective in achieving near-term missions (*e.g.,* the Manhattan Project), Freeman and Van Reenen's study of NIH budget doubling, which was not accompanied with equal expansion of applied research funding, suggest that such policies may have less-than-hoped-for outcomes, particularly if expenditures following the spending boost remain flat or decline in real terms. In particular, the authors conclude that adjustment costs, including the ability of the market for scientifically-and technically-trained workers to respond quickly, limit the short-term effects of such doubling efforts. This, in turn, harms the downstream commercialization opportunities associated with brief funding boosts.

Freeman and Van Reenen also note that globalization strengthens the argument for global funding of basic research while weakening the argument that any one particular nation should subsidize basic research, since the fruits of that investment in any one country are likely to yield spillover benefits worldwide. At the same time, they note that the argument for subsidizing applied research, which may be commercialized more quickly in any one region, increase with globalization.

Boosts in basic research funding can make valuable contributions even without attendant support for applied funding, as the positive spillovers from DARPA's research efforts, the Space Program, and even Israel's experience with spillovers from military spending to their IT sector demonstrate.

It may also be possible to support applied research and commercialization without targeted funding increases by increasing R&D tax credits, as Bloom *et al.,* (2002) and Hall and Van Reenen (2000) describe.

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Question 2. How can the United States best take advantage of the results of federally-funded research before they are picked up by other nations?

Answer. My understanding of research on this question is that the answer involves elements of both hope and concern.

The element of concern is that models and large scale quantitative studies of knowledge generation and diffusion agree with casual empiricism that much basic research diffuses widely and with some speed to researchers at the global frontier regardless of where they are located.

While this may have some deleterious effects for U.S. industry and the workforce and may appear to lower the rate of return on Federal investment in science, I think that economists generally agree that the benefits of diffusing science outweigh the potential benefits of secrecy: As Freeman and Van Reenen (2009) note, the everyone would benefit if a cure for cancer were found, regardless of whether that cure were identified in the U.S., Europe, or Asia and regardless of the location of original knowledge on which the discoverers of that cure built.

That said, evidence suggests that basic scientific knowledge diffuses more quickly towards commercialization in the regions close to its discovery. Thus, the U.S. has an inherent advantage in building upon and commercializing basic research relative to regions and countries that are more geographically distant (see, *e.g.,* the classic and often reexamined study by Jaffe, Trajtenberg, and Henderson, 1993).

In this regard, the Earth is very far from flat. Two key factors appear most important to the ability of a country to benefit from its own discoveries: (1) the overall strengths of its research and innovative capacities and (2) the ability to link the results from basic research to entities that can commercialize those efforts. Historically, the U.S. has been a leader in each of these areas, due to substantial investments in university research and the strength of technology licensing and venture funding (including venture capital) (Furman, Porter, & Stern, 2002). Ensuring that these areas sustain high levels of investment and competitiveness will support the local commercialization of federally funded research.

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Question 3. What innovative, funding-neutral policies should the Federal government pursue that it is not currently?

Answer. I believe that there are a few options that could be pursued to support science and innovation that would not require additional Federal funds. I list a few recommendations below and elaborate on these thereafter:

(1) Implement a program to support high-skilled immigration

(2) Require that Federally-funded research projects include support for and a mandate for supported scientists to deposit research materials associated with federally-funded research

(3) Require that licenses for technology supported by Federal funding be disclosed and non-exclusive

(4) Institutionalize the evaluation of federally-sponsored research—require recipients to identify the fruits of sponsored grants and consider these as relevant (though not dispositive) when deciding upon future funding.

(5) Shift existing tax structures to ensure that prices more accurately reflect actual costs; doing so would enable the price mechanism to provide appropriate incentives for innovation and the associated burdens on firms and individuals could be alleviated via revenue-neutral tax rebates.

High Skill Immigration

The first, and most often-discussed of these would be a program supporting high-skilled immigration or giving individuals. Economists who study innovation have undertaken a number of useful projects on this topic. Descriptive statistics note the over-representation of immigrants and first-generation Americans among Americans receiving patents and among the population of high tech entrepreneurs. More structural analyses demonstrate that admission of additional high-skilled immigrants—for example, through H1–B visa expansion in the 1990s—yields benefits, in terms of patents, innovation, and the size of the science and engineering workforce.

Some well-done academic work ont these topics has been conducted by William Kerr of Harvard Business School and Jennifer Hunt of Rutgers University. Two of their relevant papers include:

- William R. Kerr & William F. Lincoln (2012) "The Supply Side of Innovation: H–1B Visa Reforms and U.S. Ethnic Invention," *Journal of Labor Economics,* vol. 28(3), pages 473–508, 07.
- Jennifer Hunt & Marjolaine Gauthier-Loiselle (2010) "How Much Does Immigration Boost Innovation," *American Economic Journal: Macroeconomics,* vol. 2, pages 31–56.

While the politics of supporting high-skilled immigration may be difficult, academic research on this topic suggests that the addition of highly-trained immigrants yields improvements in science and innovation that would otherwise not have been achieved.

Disclosure requirements for licenses associated with federally-sponsored research

A second, budget-neutral recommendation is that all licensing transactions associated with Federally-sponsored research be disclosed, not concealed. In nearly all cases, the *results* of Federally-sponsored research are made accessible through the academic process of publication and presentation, the exchange of materials (such as tissue samples or cell cultures) and licensing contracts often occur without any disclosure.

This secrecy can inhibit downstream research based on Federally-funded projects. This secrecy over technology licensing has developed in part as a result of university Technology Licensing Offices' (TLOs') efforts to maximize fees and to protect the strategic concerns of licensees'. The potential value to society, however, of this disclosure likely exceeds the value of secrecy in this case. Making disclosure a requirement of funding to report the existence of, parties to, and broad features of each transaction related to the products of Federally-sponsored research would help untangle a legal web and support commercialization and downstream research efforts. This could be facilitated by a standardized, accessible database, which could be managed by the National Science Foundation and could be managed relatively cheaply, in the model of ClinicalTrials.gov. (Fiona Murray, Scott Stern, and I articulate this suggestion in the co-authored paper, "More for the research dollar," (2010), *Nature,* 468, 757–758 and the text above is based closely on text in that article.)

Require deposit of research materials associated with federally-funded research

Researchers studying the economics science suggest that establishing rules and practices that maximize the productivity of research *in the long term* can increase the rate of return of current Federal R&D funding. Implementing this approach, however, can create inconveniences or push-back from current grant recipients.

One example of how short-term researcher interests were overcome by long-term plans arises in the effort to sequence the human genome. The disparate, often competing efforts (which included the U.S. National Institutes of Health and the UK Medical Research Council) introduced rules (called, the "Bermuda Rules," which required publicly funded researchers to disclose their sequencing information every day. Whereas researchers were previously able to monopolize their information for weeks or months, the Bermuda Rules ensured that the public could benefit from this information essentially immediately and enabled complementary research and downstream work on the genome to progress more swiftly.

While this type of disclosure is unique to the case of the genome sequencing effort, the general lesson that the deposit and broad sharing of research materials speeds complementary work and downstream work has wide application to Federally-sponsored research projects. (Fiona Murray, Scott Stern, and I articulate this suggestion in the co-authored paper, "More for the research dollar," (2010), *Nature,* 468, 757–758 and the text above is based closely on text in that article.)

Institutionalize evaluation of Federally-funded research

A policy that is simple in theory, though substantially more difficult in practice would be to institutionalize the evaluation of federally-sponsored research. Part of this effort could be built on grantees' self-reports about the outcomes of federally-funded research. This could be achieved in a number of ways, including requirements that Federal funding identify the fruits of sponsored grants, either as requirements of receiving year-to-year funding, or as final reporting requirements, or as requirements for future grant applications. These outcomes should then be considered (though they should not be the only factors considered) when individuals or firms apply when deciding upon future funding.

Shift existing tax structures to ensure that prices reflect actual costs (to the extent possible)

The most general of my recommendations is likely also the most controversial. By ensuring that negative externalities (like pollution and products with deleterious health effects) do not result in prices that involve implicit subsidies, the costs of fuel and other substances that involve such negative externalities will rise to a degree that fosters innovation. The burdens that such prices impose on firms and individuals of more limited means could be ameliorated with lump sum tax rebates. Ensuring that prices reflect marginal costs, however, will support the appropriate incentives for innovation. I recognize, however, that such efforts (*e.g.,* the Acid Rain Program and potential carbon tax) face substantial political difficulties.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. AMY KLOBUCHAR TO JEFFREY L. FURMAN, PH.D.

Question 1. Your testimony mentions that one way we can improve the COMPETES Act is through initiatives supporting industry commercialization of university-generated ideas. Can you expand on how we can work to promote getting these projects into the market, as well as what promoting university research does for our international competitiveness?

Answer. The issue of technology commercialization is one of the more well-researched topics in the economics of innovation. Research in this area has addressed the commercialization of university-generated technology in a number of ways that related to U.S. competitiveness and technology policy. These include:

- *Comparisons of university commercialization efforts across countries:* These studies generally conclude that the United States is among the world leaders in this effort, as a consequence of the historical role of American universities in collaborating with for-profit companies to achieve commercialization, in part because of policies that enable faculty to work with private companies when continuing their academic pursuits, and in part because of the Bayh-Dole Act.
- *Assessments of specific programs that support technology commercialization:* These include the Bayh-Dole Act, the "professor privilege" (to patent and commercialize lab research), university intellectual property policies, the development and behavior of Technology Licensing Offices, among others. My reading of these studies is that they support the conclusion that the United States pursues policies supporting technology commercialization to a greater degree than other industrialized counties. The most recent studies of the Bayh-Dole Act suggest that it continued growth in university-industry relationships that existed prior to the Act's passing, but that it has effectively supported commercialization in the United States and that it has become a model for other countries' efforts at commercializing technology (see Mowery *et al.,* 2001, and Mowery & Sampat, 2005). One of the most sophisticated analyses of the Bayh-Dole Act in the United States (Hausman, 2012) suggests that, "long-run employment and payroll per worker around universities rise particularly rapidly after Bayh-Dole in industries more closely related to local university innovative strengths." That is, the results suggest that Bayh-Dole had a statistically and economically meaningful positive impact on employment and worker earnings in geographic regions and industries matched to local university research strengths.

While suggesting that the U.S. is at the forefront of global efforts to commercialize university-generated technology, this research does not imply that improvements are not possible.

Some improvements can come from university policies. Recently, a number of technology licensing offices have been moving away from a model in which they attempt to maximize university licensing revenues and towards a model in which they maximize the diffusion of knowledge generated by universities (Siegel *et al.,* 2003). As well, Siegel and Phan (2005) note that improving university management practices, training for students and faculty, and coordinating engineering schools with business schools could improve university-industry technology transfer.

Public policies can support university efforts by ensuring that all licensing transactions associated with Federally-sponsored research be disclosed rather than concealed. This secrecy can inhibit downstream research based on Federally-funded projects. This secrecy over technology licensing has developed in part as a result of university Technology Licensing Offices' (TLOs') efforts to maximize fees and to protect the strategic concerns of licensees'. The potential value to society, however, of this disclosure likely exceeds the value of secrecy in this case. Making disclosure a requirement of funding to report the existence of, parties to, and broad features of each transaction related to the products of Federally-sponsored research would help untangle a legal web and support commercialization and downstream research efforts. This could be facilitated by a standardized, accessible database, which could be managed by the National Science Foundation and could be managed relatively cheaply, in the model of *ClinicalTrials.gov.* (Fiona Murray, Scott Stern, and I articulate this suggestion in the co-authored paper, "More for the research dollar," (2010), *Nature,* 468, 757–758 and the text in this paragraph is based closely on text in that article.)

Expanding R&D tax credits and providing subsidies for risky commercialization efforts are other programs that have, historically, been employed to support university-industry technology transfer efforts. Research suggests that R&D tax credits can, indeed, support such activities, although the rate of return suggests that these are not a panacea (see Bloom *et al.,* 2002, and Hall and Van Reenen, 2000). Research on R&D subsidies is more mixed, with some studies suggesting that public R&D subsidies crowd out private investment fully (Wallsten's (2000) study of the SBIR program suggests this, for example) and other studies suggesting that public support supplements rather than simply replaces private investment (David *et al.,* 2000). Overall, research in on subsidies suggests that their success may depend on the details of particular programs.

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Question 2. I worked to include university commercialization reports in the COMPETES Reauthorization Act. I understand measuring the long-term economic impact of the COMPETES Act programs is inherently difficult—it is often difficult to trace any specific breakthrough or innovation all the way back to a specific research grant, additionally, these projects take time. What is the best way to measure the success of these programs? What indicators should we look to? For example, is there a way to estimate how many jobs are created by a program or by the Act?

Answer. Assessing the impact of university commercialization or any efforts to support science or innovation is both an important and difficult task. Some of the issues and difficulties are outlined in the Siegel papers cited above. The ideal indicators that one would like to have include indicators of knowledge outputs (*e.g.,* patents, papers, students trained), indicators of commercialization (*e.g.,* new firms, new products, and new jobs). Two difficulties, however, are (a) that it is difficult to obtain useful measures of inputs (*e.g.,* dollars spent on research by universities and firms) that can be used to compare with the outputs in order to compute productivity and (b) that, even if one could obtain those measures, it is difficult to identify what economists call "counterfactuals," which refer to what would have occurred in the absence of the support or policies.

Economics has made substantial advances in policy evaluation (Imbens and Wooldridge, 2009), some of which has been incorporated into recent evaluations of science and innovation policy (Furman, *et al.,* 2012). Estimating the impact of public policies on employment is made particularly difficult by the problem of knowing what would have happened in the absence of such policies. The Hausman study of the Bayh-Dole Act described above is one of the few recent studies that credibly assesses the causal impact of an innovation policy on employment outcomes.

By designing public policies with evaluation in mind (*e.g.,* by including natural variations in the timing of implementation, by including variations in specific policies across regions, etc.), however, it may be possible to lay the ground work for more systematic evaluations of their effects. Each of the papers referenced below describes ways to do this and I would be happy to discuss possibilities further.

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RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO DR. PETER LEE

Question 1. Federal funding for physical science and engineering basic research increased at a faster rate in the past five years than in the preceding decade, but applied research funding has declined with inflation. What might be the competitive implications of increasing the funding for basic research as compared to flat or even declining funding for applied research?

Answer. In computing research, distinctions such as "basic" versus "applied" don't really apply, and advances in capabilities do not necessarily follow a linear path from fundamental research to commercial application. As described in the National Research Council's "Continuing Innovation in Information Technology," [1] there is a complex interweaving of fundamental research and focused development, with innovations in academia driving breakthroughs in industry and vice versa; with ideas and technologies transitioning among fields and applications, creating opportunities in both new research and new products and markets. Individuals and projects can shift focus among discovery, invention, and engineering, and the lessons learned in any one area inform and inspire future work. This interplay between research with different drivers and timescales can be seen within Microsoft Research as well. Our research includes mission-focused, blue-sky, sustaining, and disruptive activities. Flexibility is a key attribute of our ability to meet these interrelated goals, and our researchers collaborate with leading academic, government and industry colleagues and often move in and out of universities and Microsoft business groups as the type of activities they are engaged in shift in focus. At DARPA, similar benefits have emerged from connecting research and communities across different types of projects. Therefore, when thinking about the range of research activities the government can support, for computing research, what matters is that Federal programs and agencies enable flexibility in partnerships and the flow of people among different projects and different types of projects.

Question 2. From an industry perspective, which government investments most directly contribute to the economic growth of our country?

Answer. Different government investments contribute to economic growth in different ways. Certainly investments in research and education are a critical factor. The strength of the U.S. economy and the competitiveness of U.S. companies in innovation industries reflects the quality of the people the companies can hire and the quality and quantity of research conducted by the entirety of the innovation ecosystem, including government, businesses, and academia.

Therefore, one critical element in facilitating economic growth is encouraging and supporting the conduct of research by companies, universities, and Federal agencies. This includes sustained investment by government in research, especially fundamental research, in all disciplines of science and engineering. The government can take a longer and broader view of research activities, allowing agency programs to cultivate emerging research concepts and fields. Many of the opportunities for leadership and growth by American companies will be realized through the combination of work from multiple fields and the integration of new knowledge into complex systems. Today, technology is an integral component of many sectors of the economy, including manufacturing, transportation, energy, healthcare, financial services, and

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[1] *Continuing Innovation in Information Technology;* Committee on Depicting Innovation in Information Technology; Computer Science and Telecommunications Board; Division on Engineering and Physical Sciences; National Research Council. *http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB__045476.*

national security, and therefore investment in research, and especially in computing, will make contributions across companies and geographies.

Complementing Federal support for research, the government can support and encourage U.S. industry investment in R&D by permanently and seamlessly extending the R&D tax credit. This tax credit provides a critical, effective, and proven incentive for companies to increase their investment in U.S.-based R&D. Microsoft also supports increasing the alternative simplified credit rate from 14 percent to 20 percent.

Another critical component for enabling economic growth in the U.S. is a talented and appropriately-prepared workforce. On this topic, Microsoft has released a National Talent Strategy,[2] which outlines the challenges and opportunities facing the U.S. today in improving the science, technology, engineering, and mathematics (STEM) pipeline and preparing people for the jobs of the 21st century, especially in areas such as computing and engineering. The strategy offers specific recommendations within four areas:

1. Strengthening K–12 STEM education by providing additional resources to recruit and train STEM teachers and implement Common Core State Standards and Next Generation Science Standards that will better prepare students for college and work in these disciplines.
2. Broadening access to computer science in high school to ensure that all students have the opportunity to gain this foundational knowledge and explore careers in computing.
3. Addressing our national crisis in college completion by helping students who start college to finish it faster and expanding higher education capacity to produce more STEM degrees, with a particular focus on computer science.
4. Targeting changes to high-skilled immigration both to bridge the short-term skills gap, and to help fund some of the investments in strengthening the STEM pipeline.

In all of these areas, government, businesses, and schools and universities have a role to play in increasing opportunities for American youth and enabling U.S. companies to access skilled workers in support of our global competitiveness in innovation.

Question 3. Since 2004, nearly 85 percent of R&D-related employment growth by U.S. multinational companies has been abroad. How does Microsoft's internal R&D enterprise benefit from its location in the United States, and what would make the company choose to relocate R&D abroad?

Answer. Microsoft spends 83 percent of its worldwide R&D budget in the United States. This reflects the impact we receive from enabling close collaboration between our R&D and business and product teams and the flow of people and ideas among these organizations. It also reflects the value of the partnerships we have with the U.S. innovation ecosystem, which includes our partners, our customers, and especially the American higher education system. Research universities are a critical source of ideas and collaborations, and the students who become employees at Microsoft and other R&D-intensive companies are a key conduit for keeping U.S. companies at the forefront of innovation industries.

This fundamental reliance on access to smart, skilled people is not unique to Microsoft, and it is not unique to the information technology sector. But companies across various industry sectors cannot continue to focus R&D jobs in this country if we cannot fill them here. Other countries are graduating larger numbers of individuals with the STEM backgrounds that the global economy so clearly calls for. In the short term this represents an unrealized opportunity for American job growth. In the longer term, unless the situation changes, it is possible that unfilled jobs will migrate over time to where the workforce is, and this may spur the development of economic competition in a field that the United States pioneered. In the Microsoft National Talent Strategy (as described in the response to question (2) above), there is a discussion of these issues and of the changes that would help ensure U.S. companies in general have access to an appropriately-trained workforce in the U.S.

Question 4. What innovative, funding-neutral policies should the Federal Government pursue that it is not currently?

Answer. The response to question (2) above outlines key ways in which the Federal Government supports innovation, including investment in research and in education. Examples of policy steps that can be taken within these areas include:

[2] The Microsoft National Talent Strategy is available at *http://www.microsoft.com/en-us/news/download/presskits/citizenship/MSNTS.pdf.*

- Reauthorizing the interagency Networking and Information Technology Research and Development (NITRD) program.
- Ensuring that computer science-focused projects and teachers are eligible for and included in Federal STEM education programs, especially those that provide funding for teacher professional development, research on pedagogy, and assistance to States on standards and assessments.
- Supporting interdisciplinary research and education, especially the integration of computing into STEM programs in higher education and in collaborative research.
- Increase focus on methods and incentives for retention and completion of degrees in STEM subjects, including computer science.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO DR. PETER LEE

Question 1. You note that Microsoft invests more than $9 billion a year towards research and development. However, right now, companies in the U.S. are sitting on around $1.7 trillion in cash instead of investing it in new technology, and Mr. Augustine notes that U.S. corporations spend over twice as much on litigation as on basic research. What can the government do to encourage companies to invest more in research and technology here in the U.S.?

Answer. Companies do not invest in and conduct research and development (R&D) in a vacuum. The amount of business investment in R&D, and the impact of those R&D programs reflects the quality of the people companies can hire and the quality and quantity of research conducted by the rest of the innovation ecosystem, especially universities with the support of Federal agencies.

Therefore, one critical element in encouraging company investment in R&D is complementary investment by government in research, especially fundamental research, in all disciplines of science and engineering. The government can take a longer and broader view of research activities, allowing agency programs to cultivate emerging research concepts and fields. Many of the opportunities for leadership and growth by American companies will be realized through the combination of work from multiple fields and the integration of new knowledge into complex systems. Computing is often a central element in enabling these opportunities in sectors like manufacturing, transportation, healthcare, and national security. On this front, in addition to supporting Federal investment in research in general, Microsoft also specifically is supportive of the reauthorization of the interagency Networking and Information Technology Research and Development (NITRD) program.

Another critical element in companies' conduct of R&D in the U.S. is the access to a talented and appropriately prepared workforce. On this topic, Microsoft has released a National Talent Strategy,[3] which outlines the challenges and opportunities facing the U.S. today in improving the science, technology, engineering, and mathematics (STEM) pipeline and preparing people for the jobs of the 21st century, especially in areas such as computing and engineering. The strategy offers specific recommendations within four areas:

1. Strengthening K–12 STEM education by providing additional resources to recruit and train STEM teachers and implement Common Core State Standards and Next Generation Science Standards that will better prepare students for college and work in these disciplines.
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3. Addressing our national crisis in college completion by helping students who start college to finish it faster and expanding higher education capacity to produce more STEM degrees, with a particular focus on computer science.
4. Targeting changes to high-skilled immigration both to bridge the short term skills gap, and to help fund some of the investments in strengthening the STEM pipeline.

In all of these areas, government, businesses, and schools and universities have a role to play in increasing opportunities for American youth and enabling U.S. com-

[3] The Microsoft National Talent Strategy is available at *http://www.microsoft.com/en-us/news/download/presskits/citizenship/MSNTS.pdf.*

panies to access skilled workers in support of our global competitiveness in innovation.

Finally, another step the government can take to make the U.S. environment conducive to and supportive of U.S. industry's investment in R&D is to permanently and seamlessly extend the R&D tax credit. This tax credit provides a critical, effective, and proven incentive for companies to increase their investment in U.S.-based R&D. Microsoft also supports increasing the alternative simplified credit rate from 14 percent to 20 percent.

Question 2. Dr. Lee, given that finding the brightest and most well-prepared students is so important for recruitment at a high tech firm like Microsoft, what specific measurements would tell us which universities are best educating their students in the STEM fields?

Answer. As the U.S. economy increases shifts to a focus on innovation industries, universities and other organizations will be critical in preparing the workforce of the twenty-first century. The Bureau of Labor Statistics projections forecast that occupations that require post-secondary education will grow faster than those which require a high school diploma or less.[4] However, as various institutions of higher education serve different populations and train people for different jobs and fields, it is difficult to suggest specific metrics. However, there are some key areas to watch. One is college completion—whether students are able to achieve the degrees and credentials that twenty-first century jobs require. Another is retention of students studying in STEM fields. According to analyses done for the President's Council of Advisors on Science and Technology, fewer than 40 percent of students who enter college intending to major in a STEM field complete a STEM degree.[5]

Finally, it is worth noting that information technology is becoming a critical element of research and work in all of the STEM fields. Students in STEM areas would benefit from exposure to computing principles and experience with how information technology applies within their field as part of their educational programs.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. AMY KLOBUCHAR TO DR. PETER LEE

Question. I worked to include university commercialization reports in the COMPETES Reauthorization Act. I understand measuring the long-term economic impact of the COMPETES Act programs is inherently difficult—it is often difficult to trace any specific breakthrough or innovation all the way back to a specific research grant, additionally, these projects take time. What is the best way to measure the success of these programs? What indicators should we look to? For example, is there a way to estimate how many jobs are created by a program or by the Act?

Answer. As noted above, it is difficult to measure the economic impact of individual programs in an interconnected system such as the innovation ecosystem in the U.S. This is particularly challenging in the information technology space, where new products and capabilities build on a broad collection of technologies and advances and can't be traced to a single research paper or patent or graduate student.

In the longer term, the overall benefit to the economy due to investments in research can be seen in the emergence of new industries. The National Research Council's "Continuing Innovation in Information Technology" describes eight entirely new product categories that ultimately became the basis of new billion-dollar industries, including broadband and mobile technologies; microprocessors; personal computing; the Internet and the Web; cloud computing; enterprise systems; entertainment technologies; and robotics.[6] Federal investments in research, mostly in academia, played a critical role in all of these areas, both by funding specific re-

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[4] From the U.S. Bureau of Labor Statistics' occupational employment and job openings data, projected for 2010–2020. Overview available at *http://www.bls.gov/ooh/About/Projections-Overview.htm.*

[5] President's Council of Advisors on Science and Technology. Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. *http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final__2-25-12.pdf.* This report derived the number from U.S. Department of Education, National Center for Education Statistics, 2003–04 Beginning Postsecondary Students Longitudinal Study, Second Follow-up (BPS:04/09), See Appendix C of PCAST Report.

[6] *Continuing Innovation in Information Technology;* Committee on Depicting Innovation in Information Technology; Computer Science and Telecommunications Board; Division on Engineering and Physical Sciences; National Research Council. *http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB__045476.*

search areas that opened up new opportunities and supporting the education of the scientists and engineers who powered the new products and companies.

Similarly, the connections between investments in information technology research and job creation are hard to measure narrowly. Looking at employment just in the information technology sector does not reflect the value that advances in information technology capabilities bring to sectors across the economy, including financial services, manufacturing, healthcare, and others.[7] In addition, there is the impact of high tech companies on local economies. It has been estimated that for every high tech job created in a metropolitan area, five additional local jobs are created outside of the high tech industry.[8]

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO JOHN L. WINN

Question. What innovative, funding-neutral policies should the Federal Government pursue that it is not currently?

Answer. I propose making STEM a priority for many K–12 and higher education grant programs.

Require Title II to have a STEM focus in state strategies.

Make Title II STEM programs be more competitive.

Give scholarship programs a STEM priority component.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. AMY KLOBUCHAR TO JOHN L. WINN

Question. I worked to include university commercialization reports in the COMPETES Reauthorization Act. I understand measuring the long-term economic impact of the COMPETES Act programs is inherently difficult—it is often difficult to trace any specific breakthrough or innovation all the way back to a specific research grant, additionally, these projects take time. What is the best way to measure the success of these programs? What indicators should we look to? For example, is there a way to estimate how many jobs are created by a program or by the Act?

Answer. The USDOE needs to develop common metrics toward improving the STEM education and workforce development and require these metrics to be reported on. Once data is being collected on common metrics, they should be analyzed and used to drive future policy on what works. These evaluations are often put aside as the government moves on to next year's grants.

The Federal Government should focus on scaling effective programs in STEM fields. One major problem is local successes are never really scaled to make a larger impact.

The state of Florida has done a fabulous job of tracking students from education through employment. Look to their program. There are two issues: (1) How many more skilled workers do we have going into relevant STEM fields and (2) How many new jobs are being created. Not sure how to measure the second one as jobs tend to follow innovations developed in the market place and based on consumer demand.

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[7] Of the people working in computing occupations, 9 percent are in information services, 12 percent are in financial services, 36 percent are in professional and business services, 7 percent are in government and public education services, and 12 percent are in manufacturing. Georgetown University Center for Education and the Workforce report on STEM (October 2011), by Anthony P. Carnevale, Nicole Smith, and Michelle Melton, available at *http://cew.georgetown.edu/stem/*.

[8] Enrico Moretti, *The New Geography of Jobs* (2012).