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THE FEDERAL RESEARCH PORTFOLIO: CAPITALIZING ON INVESTMENTS IN R&D

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED THIRTEENTH CONGRESS

SECOND SESSION

JULY 17, 2014

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED THIRTEENTH CONGRESS

SECOND SESSION

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THE FEDERAL RESEARCH PORTFOLIO: CAPITALIZING ON INVESTMENTS IN R&D

THURSDAY, JULY 17, 2014

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

The Committee met, pursuant to notice, at 2:36 p.m. in room SR–253, Russell Senate Office Building, Senator John D. Rockefeller IV, Chairman of the Committee, presiding.

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

The CHAIRMAN. As I've explained to one of you already, this is sort of a bad afternoon and I don't give a hoot because, if there was nobody here, I'd be even happier because then I'd get you all to myself, and I'd keep you for 2 hours and we'd just have an incredible conversation. But, everybody, by three o'clock, virtually everybody is out of here, because they all have to go through this miserable process of going back home and going to fundraisers and doing political speeches and all of this stuff, which John Thune doesn't have to do because he's an icon in South Dakota.

[Laughter.]

Senator THUNE. Yes, right.

The CHAIRMAN. Well, that's new. At least it's new.

And, you know, John, and Amy is going to be here. And I think it'll just be us.

I think your general impression is accurate, that we get nothing done in the Senate, but that doesn't mean that we can't. And you have an example right here; these two people. Now we're not the same people, we belong to different political parties, we have different philosophies on some things but our attitude, since we like each other——

[Laughter.]

Senator THUNE. Yes. Yes.

I'm sorry, I missed the cue.

The CHAIRMAN. We look for ways to cooperate. Though, rather than looking for ways to not cooperate, we cooperate to cooperate. And, as a result, we're going to be able to hand up a bill here very shortly, which I'm going to show you what we've done. And we worked together. And that was a harder stretch for him than for me because he's under more pressure sometimes. I mean, Democrats can always be irresponsible; right?

[Laughter.]

The CHAIRMAN. And then, his predecessor was a lady named Kay Bailey Hutchison from Texas. And she was fabulous; absolutely fabulous. And she was a classic moderate Republican; right? A little bit of old school?

Senator THUNE. She was a conservative, but yes.

[Laughter.]

The CHAIRMAN. Yes.

No, but I mean in her——

Senator THUNE. Yes, demeanor.

The CHAIRMAN.—demeanor.

Senator THUNE. In her demeanor. Yes, that's right.

Very nice.

The CHAIRMAN. Yes.

You know, I just came from the National Youth Science Foundation Luncheon where there were 200 of the two smartest people from every state in science, technology, engineering and math were there. And they all got really boring speeches except mine, which is absolutely terrific.

[Laughter.]

The CHAIRMAN. It just gives you such a sense of joy to know that there are people out there like that.

And, John, I'm sure yours were just as good.

But, Kay Bailey—we had this America COMPETES Act, which we're going to hold up the second version of it, third version of it, that was saddled, a number of years ago, in the center of the Senate aisle on a bipartisan basis by a unanimous consent. It was a $45 billion bill. That's not something that people ordinarily sign onto quickly. And there were five holds on the Republican side. And Lamar Alexander and I had been governors together, and his wife is on my wife's public television board. And Kay Bailey Hutchison is just a really good friend and I still send her flowers on Mother's Day.

None of this has anything to do with this hearing.

[Laughter.]

The CHAIRMAN. But, if you just be patient, it's almost over.

And so, this is the way we did the America COMPETES bill; a $45 billion bill.

Kay Bailey said, "This is a little rich."

I said, "What if I take a billion off?"

You know when you say, "What if I take a billion off?" that sounds really good; right? It's a lot of money. So we did that.

Then, she said "Well there's this program," and some part of it that I don't really like.

So I called up my committee staff head here and I said, "Do we really need that?" She said, "No, actually we don't."

So I said, "Kay Bailey, the billion is gone, the program is gone, Lamar Alexander is obviously devoted to education," from his educational background, "went and cleared all the Republican holds." And we passed it by unanimous consent without moving that one afternoon.

So things used to be like that. They can still come to be like that. It won't be quick, but do not get discouraged. OK.

Senator THUNE. Here, here.

The CHAIRMAN. I really appreciate your being here. We had a great hearing yesterday, but this is going to be a better hearing. There just won't be as many members here because they're all home going to their public libraries to read serious books; right?

Senator THUNE. Yes.

The CHAIRMAN. I've been working on this whole area for a long, long time. I'm really honored to be chair of this committee and to work with John Thune, because we do have jurisdiction over it, which is a complex word but it's the oversight of NIST, NSF. You know all the places which don't get enough attention. They get more attention for doing cybersecurity but otherwise they don't. But they're incredible important. But unless you decide they're important then you feel free to go and cut. Now there's a lot of cutting going on in Congress this day and that's something we're going through and that's going to be difficult.

But there can be absolutely no question investing in science, technology and innovation and educating our young people is critical to our future. And that's what you say, Vint, in your, Dr. Cerf, in your opening statement and I think we should all be grateful that our country's leaders have had wisdom and the patients to make over the years these investments because they make a real difference in peoples' lives. You do it for the cerebral excitement of it but you also do it for the public good. I mean, that's just part of what you do.

Investments never change things over night. Americans always want things to be changed overnight, but when they do things and you've been involved with them, they're game changers. And funding for the agencies like the National Science Foundation, NIST, just doesn't mean another scientist in a lab somewhere; quite the contrary.

The money that we put into basic research in understanding the world around us has a real world impact and it creates new ways, one, to protect our loved ones by better identifying dangerous counterfeit drugs; second, to secure our homeland by being able to smell even small amounts of explosives; and three, to interact with the world by providing seed funding and new technologies for companies that transform the Internet, communications, and mobile phones, and a whole lot of other things.

That's why I've been so happy to support Federal funding. John's going to get mad at me in a minute, but there have been a bunch of Senators, before I got here from West Virginia, none of them have ever voted for a foreign aid bill or a foreign assistance bill. They considered that to be a waste of money, money that could be spent on West Virginia or something else and there has almost never been a foreign aid bill that I haven't voted for. And that's just a change. I'm different in that way and people have come to accept that. And it doesn't make me popular, but it makes me do my job.

So that's why I support Federal funding for research and development, R&D, for education in science, technology, engineering, and mathematics; STEM. That's also why I've been a huge champion, along with John, for the American COMPETES Act of 2007 and 2010; we're going to hold up the next one in a few minutes.

Over the past few months, I've received some amazing numbers on the impact of programs addressed in that COMPETES Act.

Back in 2001, I worked on legislation to create the Robert Noyce Teacher Fellowship Program, which was strengthened in 2007, in that COMPETES Act. As of last year, the Noyce Scholarship—see I love reading these things. The Noyce Scholarship Program is expected to help produce over 12,000 math and science teachers in high-need areas.

Well, Senator Thune and I both come from high-needs areas; from rural states with a lot of people who don't get to do what people in more urban areas do.

In 2010, the COMPETES granted every Federal agency the authority to award prizes for solutions to difficult problems. Since then, the website *Challenge.gov* has hosted over 200 challenges with over 16,000 Americans participating. That's good. That's not 160,000 but it's 16,000. That's good. Ongoing challenges are working to better measure pollution; reduce hospital readmission; to bring down the cost of solar energy; and just tons of other areas.

If this country is going to build on these tremendous results, we must continue to defend scientific research and to make it a priority. Make it a priority. Given our government's long and successful track record in supporting research and development, I'd like to think that it doesn't need defending. But, you know, I'm wrong. It does; vigorous defending, which is why this is important.

We know that our science agencies have suffered because of long-term funding reductions. That's not just the work but the morale, people's future plans. It's like any time you make cuts, people start looking at their future in a different way because they figure I can't be sure the government is going to change, because nobody can predict the future that way. And, if they do, it's usually gloomy.

It's very impossible to plan long-term research when you can't even be sure of your next budget over the next couple of months. Also, we've seen proposals that would let Congress decide what research projects are worthwhile. Now this is something which makes me very hot under the collar. Congress has no business deciding what research projects are worthwhile. I mean, you know, we've got scientists in the Congress and they can be helpful. We've science committees and that kind of thing. But, having served on this committee and worked with the Senate Science and Technology Caucus, I know that scientists, through grant competitions and peer review, are best able to make those decisions. Congress wants to but you know what's best, and your colleagues.

On his deathbed, and I love this story, John. In 1969, Senator Thune, President Dwight Eisenhower told a friend that in his experience, I've never read this before and I've never heard this before, "scientists were", on his deathbed mind you, "were one of the few groups in Washington who seemed to be there to help the country and not help themselves."

Our House colleagues would substitute their own opinions for those. The scientific community would be wise to remember those words.

Today, I plan to—now comes my big moment. John, we're going to hold this bill up together. See?

This is the 2014 America COMPETES bill, which I haven't yet read. This is why I'm not going to give it to you.

[Laughter.]

The CHAIRMAN. This bill would make it clear that the United States is committed to leading the world in science and engineering. That means getting the kids excited about STEM, funding a wide-range of research and making sure that the best research results make it to the marketplace, which is all that counts.

There are already so many examples of federally-funded research making our Nation and our economy stronger. That's why I'm very glad to see Dr. Vint Cerf here today. It really was not Al Gore; it was Vint Cerf who, at DARPA, started the whole Internet business. And Dr. Cerf will explain it took several decades of incremental work by scientists. See that's what is so important. Everybody wants a quick solution, a quick answer. It doesn't work that way. And that's the difference with the private sector. The private wants to get a result quickly or relatively quickly. They'll hang in some of the big ones for a while and put up risk money, but at some point they've got to have a result.

The Federal scientists know that sometimes the risk of failure is your best friend, because you learn from why you failed and, rather than have your program canceled, you have to have it defended because you learned from that and you go on to do what you do.

Netscape, Yahoo!, Google, you know, all of those things would be nowhere without all of you. And they pursue their business ideas because of what you've done.

Our challenge is to make sure that the next Internet is developed by the United States, not in a laboratory in China, India, or Europe. And I'm not xenophobic that way. It's just I want it that way. I mean, we used to have those magnificent institutes in India; you have to be brilliant to get in and brilliant to get out. They'd all come over here and they'd do their graduate study and they'd stay here and they'd work here. And now, increasingly, there and in other countries they don't. They go back to their own countries. And I can't criticize that, because their own countries need them too. But it was just wonderful when they were all staying here and working and starting up businesses and it was exhilarating. And Europe, too.

So unless we choose to support science in the country, and it is a choice, it's always a choice, I'm afraid that the next world-changing innovation will not belong to us. And that's why I'd like to invite all of my Senate colleagues to work with Senator Thune and myself on a 2014 COMPETES reauthorization to ensure that our country continues to lead. And that's the end of me.

Senator Thune.

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

Senator THUNE. Thank you, Mr. Chairman.

Thank you for holding this hearing to consider the Federal role in scientific research and development and how best to capitalize on Federal investments.

I join you in welcoming our witnesses to today's hearing, which presents us with a good opportunity to discuss the impact of the

United States R&D enterprise on our economy and our society overall. Among individual countries, the United States is by far the largest investor in public and private R&D, comprising 30 percent of the global research and development total. Past and current budget realities, however, underscore the importance of maximizing our Federal investments that so we can get the biggest bang for our buck, and should encourage an examination of ways to leverage even more private sector resources to expand the reach of our R&D.

The America COMPETES Acts of 2007 and 2010 were designed to set our science and technology R&D priorities and serve as the authorizing vehicles for the National Science Foundation and the National Institute of Standards and Technology under our Committee's jurisdiction, as well as for the Department of Energy's Office of Science.

I know you, Mr. Chairman, and former Ranking Member Kay Bailey Hutchison worked together on the America COMPETES Acts of 2007 and 2010, and I look forward to reviewing the legislation that you just put forward and that your staff is in the process of developing for discussion, and evaluating opportunities for consensus as we go forward.

At some level, there is broad bipartisan consensus that the Federal Government should play a significant role in promoting scientific research, especially basic research. As Dr. Cerf points out in his testimony, businesses can rarely support sustained, long-term, high-risk research in the same way the Government can; this is especially true when the benefits, though potentially large, are diffuse. But, once we get beyond the high-level agreement, the nuts and bolts of Federal funding can get quite challenging.

As our colleagues on the House Science Committee have noted, it is not hard to find examples of federally funded research that sound more like the pet projects of eccentric billionaires than matters worthy of limited taxpayer dollars. Plus, even when we accept the scientific merits of R&D, there's no shortage of worthwhile projects with more clear-cut ends that compete with basic research for funding.

In this Committee, we've heard previous testimony about the importance of funding research intended to stimulate advanced manufacturing, improve forensic science, and bolster cybersecurity. All of these are laudatory goals, but some may be achieved through means other than direct Federal spending. For example, I introduced an amendment to the tax extenders legislation in May that would simplify and make permanent the R&D tax credit. This tax credit encourages businesses to continue investing in R&D and promotes jobs and manufacturing throughout the country.

In my view, the Federal R&D enterprise is at its best when it supports important basic research that is foundational to discovery. For example, in my home state of South Dakota, researchers a mile below the surface at the Sanford Underground Research Facility, or SURF, in Lead, South Dakota have been conducting a world-class experiment to detect dark matter. While the applications of this research are yet to be fully understood, such research contributes to our understanding of how the universe works. I'm pleased to note that NSF and DOE recently announced that they have jointly selected a portfolio of projects for the second generation of dark matter, direct-detection experiments that will include another new experiment housed at SURF.

These existing and future dark matter experiments, which present compelling goals and opportunities for U.S. leadership in the physical sciences, include more than 100 collaborators representing 17 universities around the world, including South Dakota School of Mines & Technology and the University of South Dakota, as well as national laboratories in the United States, the U.K., and Portugal.

Federal support for fundamental research, such as that underway at SURF and at universities across the country, can provide the foundation for many new innovations. These discoveries often provide useful applications far afield from the original focus. Yet, to help recognize potential applications, a recent National Academy of Sciences report highlighted the need to improve the metrics and measures that track and evaluate these publicly funded research programs and their ultimate impacts on society.

Along these lines, I look forward to hearing from our witnesses today about ways to better maximize the benefits of federally funded research, as well as barriers that are inhibiting innovation. I'm also interested to hear about any challenges our witnesses in the private sector and university community have faced in investing in long-term research, as well as the obstacles they've confronted in attracting and retaining foreign-born students and workers in STEM fields. I'd also like to hear from the witnesses about what policies beyond direct funding from Federal agencies, could help to unlock new sources of R&D from the private sector.

I want to thank you all for your participation and for taking time to share your insights with the Committee this afternoon, and I look forward to your testimony.

Thank you, Mr. Chairman.

The CHAIRMAN. All right. Now it's your turn unless you'd like us to talk more.

[Laughter.]

The CHAIRMAN. Dr. Cerf, you are going to be first. I've already read your testimony but I'd like to hear it again.

STATEMENT OF VINTON G. CERF, VICE PRESIDENT AND FICEF INTERNET EVANGELIST, GOOGLE; MEMBER, NATIONAL SCIENCE BOARD

Dr. CERF. Thank you very much, Mr. Chairman and Ranking Member Thune.

I must confess to you, after listening to both of your opening remarks, I almost feel like I should stay silent because, you know, you basically just gave my speech. But if you can tolerate a few additional remarks, I would be honored to continue.

There is no substitute for deep understanding of natural and artificial phenomena, especially when our national and global well-being depends on our ability to model and make predictions regarding them.

Government support for basic and applied research is crucial. Not only does it bring great civil and economic benefits, but the government also has the unique capacity to sustain this kind of effort. You are all well aware of the fundamental scientific paradigm. Theories are developed to explain observations or to speculate on how and why things might work. Experiments are done to validate or refute the predictions of the theory. And theories are revised based on experimental results.

Basic and applied research go hand-in-hand. Basic research tries to understand and applied research tries to do. And often, one must pursue both in the effort to uncover new knowledge.

The Internet is a great example of how successful applied research projects develop. It took 10 years for the Internet to reach operational status. It's still the subject of research and further development as new and, often, unexpected applications are invented every day.

Validation of basic research may take a long time. Results are not always guaranteed. Consider the recent discovery of the Higgs boson. Peter Higgs and his colleagues postulated the existence of this fundamental particle around 1954, but it has taken 50 years, I'm sorry, 1964, but it has taken 50 years to achieve the experimental capacity to test the theory. Research also requires humility. Every scientist must be prepared to cast aside or revise a pet theory if measurement and observation contradict it.

Failure is the handmaiden of wisdom in the scientific world. Understanding the reason for failure is sometimes even more important than positive results. It may pave the way for deeper understanding. The freedom to accept the potential of failure makes the difference between an incremental refinement and a breakthrough. Einstein's special and general Theory of Relativity shattered the complacency of the Newtonian model of the Universe.

Research into the nature of the atom led to the development of quantum field theory. Relativity and quantum field theory have not been reconciled. And now we believe that the physics of the very small are extremely relevant to the study of the universe at large.

If we've learned anything over the course of the past 100 years, it is that we know less than we once thought we knew about the world around us. For scientists, this only means that discovery awaits at every turn.

Sustainable businesses are rarely in position to invest in long-term research. The U.S. has benefited from underwriting this kind of work as exemplified by the research programs of DARPA, NSF, NIH and NIST; among many others. Consistent and increasing support for basic and applied research and advanced development has been the source of most advancements in science and technology in the last 70 years and has played a large role in making the American economy the envy of the world. In this area, the Congressional committees, focused on scientific research and development, have extremely important roles to play.

We're living through a renaissance of computing that will transform our ability to understand global phenomena. New disciplines, such as computational biology, computational chemistry and computational physics, use increasingly detailed and accurate models to make predictions that we can test in the laboratory. The resulting breakthroughs could help people live longer, healthier and more productive lives. As Richard Hamming famously observed, "The purpose of computing is insight not numbers."

The 2013 Nobel Prize in chemistry went to three NSF researchers for their computer models of molecular processes. It's sometimes said that we're all born natural scientists but that our educational system erodes this curiosity with poorly constructed curricular content and style of presentation. Computers and networks may have a role to play there as well.

Along with the Association for Computing Machinery, I believe every student should have some exposure to programming. I've been a strong proponent of the proposition that computer science should be a required part of the K–12 curriculum, treated on a par with the other STEM subjects.

The Maker Movement, accelerated by the development of 3D printers and the Internet of things, is perhaps one of the most important trends in modern culture. Stimulated by NIST, NSF and the America COMPETES Act, advanced manufacturing and the Maker Movement have the potential to recapture American initiative and interest in a space that historically had moved offshore.

And, while absolutely not a panacea, massive online open courses have a transformative potential for the education system in their ability to deliver affordable, high-quality content, at scale, and individualized learning in appropriate education areas.

In conclusion, government support for basic and applied research is crucial. I am proud and privileged to serve on NSF's National Science Board. NSF's Scientific and Educational program relies on widely solicited proposals, a well-tested peer review system, dedicated and well-qualified program managers, and strongly motivated and highly effective leadership.

Successful government scientific endeavors depend upon a partnership among the research community, research agency leadership and staff, and the members of the House and Senate who are equally committed to the research. Vannever Bush got it exactly right. Science is an endless frontier. The more we learn, the more we know we don't know, and the more we must dedicate ourselves to learning and knowing more.

Thank you.

[The prepared statement of Dr. Cerf follows:]

PREPARED STATEMENT OF VINTON G. CERF, VICE PRESIDENT AND FICEF INTERNET EVANGELIST, GOOGLE; MEMBER, NATIONAL SCIENCE BOARD

Chairman Rockefeller, Ranking Member Thune, Members of the Committee, distinguished panelists and guests, I am honored and pleased to have this opportunity to participate in a hearing on a topic about which I am passionate and committed: basic research. There is no substitute for deep understanding of natural and artificial phenomena, especially when our national and global well-being depend on our ability to model and make predictions regarding them. It would be hard to overstate the benefits that have been realized from investment by the U.S. Government and American industry in research.

I am sure every member of this committee is well aware of the fundamental scientific paradigm: Theories are developed to explain observations or to speculate on how and why things might work. Experiments are undertaken to validate or refute the predictions of the theory. Theories are revised based on experimental results.

Basic and Applied Research

While the primary focus of attention in this panel is on basic research, I feel compelled to observe that basic and applied research go hand-in-hand, informing and stimulating each other in a never-ending Yin and Yang of partnership. In some ways, applied research is a form of validation because the success (or failure) of the application may reinforce or contradict the theoretically predicted results and the underlying theory. Basic research tries to *understand* and applied research tries to *do* and often one must pursue *both* in the effort to uncover new knowledge.

I would like to use the Internet as an example of applied research to make several points. The Internet was first conceived by Bob Kahn in late 1972. He and I worked together on the idea during 1973, publishing the first paper on its design in May 1974. It was launched operationally on January 1, 1983. Sponsored by the U.S. Defense Advanced Research Projects Agency (DARPA), the Internet drew strong motivation from its earlier and highly successful ARPANET and later Packet Radio and Packet Satellite projects. The Packet Satellite project also drew, in part, on the results of another project called ALOHAnet that had been sponsored by the U.S. Air Force Office of Aerospace Research (SRMA).

First, successful applied research projects like the Internet may take a long time to mature. It was ten years from the conception to the deployment of the system and required persistent funding and advocacy during and after that period, to say nothing of the research and experimentation that preceded it.

Second, while primarily an engineering and applied research project, the system did then and continues now to turn up new theoretical and analytical challenges. We are still evolving theories and models of the behavior of this complex, growing and evolving system as we measure, observe and analyze its performance. The applications of the Internet continue to drive research aimed at understanding and improving its operation or in inventing something better.

Third, serendipity has played a significant role in the evolution of the Internet's functionality and the applications it supports. Networked electronic mail emerged as a major but unplanned application on the ARPANET. The World Wide Web (WWW), initially conceived in 1989 to support sharing of research papers in particle physics at the Center for European Nuclear Research (CERN), spread rapidly on the Internet after the introduction of the MOSAIC browser by the National Center for Supercomputer Applications (NCSA) at the University of Illinois in Urbana-Champaign in late 1992 and the creation of the Netscape Communications corporation in 1994. The WWW has become the most widely-used application on the Internet. Though the WWW was conceived for a particular application, its generality, and that of the underlying Internet, has created the conditions for a cornucopia of new uses that continue to be invented daily.

Research Takes Time

Validation of basic research may also take a long time. The notion of the *inflation* of the early universe still awaits satisfactory confirmation. Postulated by Alan Guth (among others) around 1974, this year's recent results, from measurements taken by the BICEP2 experiment, suggest evidence that this theory is correct, but there is significant debate about the interpretation of the measurements. While the community awaits further corroborating or refuting experimental validation of the measurements, it is important to recognize that the means to gather potentially validating experimental data took 30 years to reach maturity. A similar observation can be made for recent discovery of a Higgs boson by the Large Hadron Collider team at CERN. Peter Higgs and his colleagues postulated the existence of this fundamental particle and its associated field around 1964 but it has taken 50 years for the experimental capacity to test this theory to reach the point where such tests could be undertaken.

It's Risky: There are No Guarantees

It is worth pausing for a moment to appreciate that research, by its very nature, cannot always guarantee results. Moreover, sometimes the results may come in the form of surprises. A canonical example is the discovery by Alexander Fleming, in 1928, that penicillium mold produces an antibiotic. He was reacting to an unexplained observation in some petri dishes he happened to notice. It was not until 13 years later in 1941 that the active compound we call penicillin was isolated. The best scientists are the ones who are alert to anomalies and seek to understand them. Nobel prizes don't go to scientists who ignore anomalies. They go to the scientists who see unexpected results and say, "huh? That's funny!" and try to find out what is behind an unanticipated observation.

Humility is called for in this space. One hears the term "Laws of Physics" as if punishment awaits anyone or anything that dares to break them. And, yet, we know these so-called laws may be only approximations of reality—limited by the accuracy of our measurement tools and experimental capacity to validate their predictions. Every scientist must be prepared to cast aside or revise a pet theory if measurement and observation contradict it.

Perhaps more important is the ability to sustain high risk, high payoff research. American industry can afford to take some risk but sustainable businesses are rarely in a position to invest in very long-term research. Venture capital, while historically willing to take considerable risk, is looking for near-term payoffs. The ability to take sustained, long-term risk for potential long-term benefit falls largely to the government. The United States has benefited from underwriting this kind of research, as exemplified by the research programs of the National Science Foundation (NSF), the Defense Advanced Research Projects Agency, the National Institutes of Health, the National Institutes of Standards and Technology, among many other U.S. Government supported research programs.

In this area, the U.S. Congress and the Committees focused on scientific research and development have the greatest roles to play. Consistent and increasing support for basic and applied research and advanced development has been the source of most major advances in science and technology in the past 70 years. The American economy has been the envy of the world, in large part because of this consistent cycle of long-term research and its application to near-term products and services.

The Importance of Failure

Failure is the handmaiden of wisdom in the scientific world. When we make predictions or build systems based on our theoretical models, we must be prepared for and learn from our failures. Understanding the reason for failure is sometimes even more important than positive results since it may pave the way for far deeper understanding and more precise models of reality. In the scientific enterprise, the freedom to take risk and accept the potential of failure makes the difference between merely incremental refinement and breakthroughs that open new vistas of understanding.

In the late 1800s it was thought that the Newtonian model of the universe was complete and that we merely needed to measure the physical constants more accurately to be able to make unequivocal predictions. In 1905, Einstein's four papers on the Photoelectric effect, Brownian motion, special relativity and mass-energy equivalence ($E=Mc^2$) shattered the complacency of early 20th Century physics. He showed that purely Newtonian notions were inadequate to explain measured observations. He compounded his impact in 1915 with the publication of his monumentally important field equations of general relativity.

Research into the nature of the atom led to the development of quantum field theory beginning in the 1920s. Efforts to reconcile its extremely counter-intuitive but extremely accurate predictions with Einstein's geometric theory of space-time have not borne demonstrable fruit. The irony of all this is that we now believe that the physics of the very small are extremely relevant to the study of the universe at large because the early universe at the moment of the so-called Big Bang was so small and dense and hot that quantum models appear to have dominated its behavior. Einstein's geometric theory simply breaks down under these conditions and provides no predictions of testable use.

If we have learned anything over the course of the past hundred years, it is that we know less than we once thought we knew about the world around us. For scientists, this only means that the territory yet to be explored is simply larger than ever and that discovery awaits us at every turn.

The Role of Computing

Richard Hamming is a legendary numerical analyst. As he famously observed: "The purpose of computing is *insight,* not numbers." Computers, computation, networking and information sharing have become essential parts of the research landscape over the past 50 years. The World Wide Web and the search engines that have evolved around it have improved our ability to share and discover information and potential research partners on a global scale. New disciplines have emerged such as computational biology, computational chemistry and computational physics. We use increasingly detailed and accurate models to make predictions that we can test in the laboratory. The 2013 Nobel prize in chemistry went to three researchers for their *models* of molecular processes. From the *Scientific American* blog:

> ". . . this year's prize in chemistry has been awarded to Martin Karplus, Michael Levitt and Arieh Warshel for their development of "multiscale methods for complex systems". More simply put, these three chemists have been recognized for their development and application of methods to simulate the behavior of molecules at various scales, from single molecules to proteins." [1]

There is a renaissance in the application of computing to research, partly driven by the vast increase in computational power and memory found in combinations of

[1] *http://blogs.scientificamerican.com/the-curious-wavefunction/2013/10/09/computational-chemistry-wins-2013-nobel-prize-in-chemistry/*

cloud and super computing. "*Big data*" has become a mantra but it is fair to say that our ability to absorb, analyze and visualize vast quantities of measured or computed data has improved dramatically in the last few decades. We can use finer and finer-grained models, improve accuracy and timeliness of predictions, thanks to these capabilities. Computational biology may lead to breakthroughs in our ability to understand genetics, epi-genetics, the proteome and the importance of flora in our digestive systems. With this knowledge, we will help people live longer, healthier and more productive lives. Our ability to understand global phenomena will benefit from this computational renaissance.

I would be remiss not to mention the *Internet of Things* that is fast upon us. The networking of common devices that surround and perfuse our society is rapidly becoming reality. From household appliances to office equipment, from industrial manufacturing to utilities, from transportation vehicles to personal monitoring equipment, we will live in an increasingly networked world. We will be surrounded by software. It is vital that we learn to design safety and security into these systems and to understand and be able to predict their aggregate behavior. This trend, too, illustrates the promise and the peril of our modern world. Cyber-security and cyber-safety must accompany our increasing use of computers, programmable devices and networks if we are to receive net benefit from these developments.

Nano-Materials

Adjacent to and actually contributing to computational capacity we find nanotechnology of increasing importance and value. Materials not found in nature have properties that defy intuition (*e.g.,* invisibility and superconductivity). Graphene: sheets of carbon molecules, arrayed in one-atom-thick, hexagonal, "chicken wire" fashion, have unexpected potential for replacing silicon in transistors, for filtering impurities from water, for conducting heat and super-conducting electricity. Carbon is becoming both the bête noir and the deus ex machina of our civilization, depending on whether it is in the form of carbon dioxide, hydrocarbon fuels, or carbon nanotubes!

In the Interest and Pursuit of Science and its Application

It is widely and correctly appreciated that science, technology, engineering and mathematics (STEM) form the basis for improving upon and making use of our understanding of how the phenomena of our world work. While there is persistent controversy regarding the supply of STEM-trained workers, there can be little doubt that there is an increasing demand in the workforce for these skills.

As a recent president of the Association for Computing Machinery (ACM) and a member of the Google staff, I have been a strong proponent of the proposition that computer science should be a required part of the K–12 curriculum. Every student should have *some* exposure to the concept of programming, not only because it promotes logical thinking but also because it is important for *everyone* to understand and appreciate the potential weaknesses in all software-controlled systems. Computer science should be treated on a par with biology, chemistry, physics and mathematics in K–12 and undergraduate curricula, not simply as an elective that bears no STEM credit.

The *maker* movement [2] is perhaps one of the most important, emerging phenomena in modern culture. The rediscovery of the joy and satisfaction of making things is contributing to a rebirth of American interest in small-scale manufacturing and pride of workmanship. The development of so-called *3D printers* has accelerated this phenomenon. Coupled with research programs in advanced manufacturing, stimulated in part by versions of the America COMPETES Act [P.L. 110–69 of 2007 and P.L. 111–358 of 2010), advanced manufacturing and the maker movement have the potential to recapture American initiative and interest in a space that historically had moved off shore.

Voluntary programs such as Dean Kamen's FIRST [3] Robotics competitions are representative of a wave of such initiatives that have the potential to rekindle the natural STEM interests of America's youth.

It is sometimes said that we are all born natural scientists but that our educational system sometimes manages to erode this natural curiosity with poorly constructed curricular content and style of presentation. Computers and networks may have a role to play here as well.

An early foray into Massive, Open, Online Classes (MOOCs) space was undertaken by two of my Google colleagues, Sebastian Thrun and Peter Norvig. They proposed to teach an online course in artificial intelligence, in cooperation with Stan-

[2] *http://en.wikipedia.org/wiki/Maker_culture*

[3] *http://www.usfirst.org/* ["For Inspiration and Recognition of Science and Technology"]

ford University. Expecting, at most, 500 people to sign up, they were stunned to find 160,000 people had applied to take the class. Critics pointed out that only 23,000 completed the course—but I defy you to provide an example of any teacher of computer science who had taught that many students *in the course of a career* let alone one class!

The early success of MOOCs has generated a justifiable excitement and formation of for-profit and non-profit efforts in this space. Serving classes of tens of thousands of students at a time, the economics of MOOCs is dramatic and compelling. A class of 100,000 students, paying $10 each, generates $1M in revenue! Plainly, the scaling is the key leveraging factor. While absolutely not a panacea, the potential for delivering high quality content and individualized learning in appropriate educational areas has a transformative potential for an educational system that has not changed much in the last 200 years.

Conclusion

In my opinion, support for basic and applied research is fundamentally justifiable based not only on the civil and economic benefits it has conferred but also on the ground-level understanding that basic research is high risk but has a high potential payoff. Only the Government has the capacity to sustain this kind of effort.

I am proud to serve on the National Science Board where I am privileged to engage with colleagues on the Board and the National Science Foundation staff. The scientific research enterprise manifests there in the form of widely solicited proposals, a well-tested peer review system, dedicated and well-qualified program managers and strongly motivated and highly effective leadership.

Successful scientific endeavors at NSF rely on a partnership among the research community, the National Science Foundation staff, leadership and board, and the members of the House and Senate who are equally committed to basic and applied research. Vannever Bush got it exactly right in his landmark report: Science, The Endless Frontier[4]. Science ***is*** an endless frontier. The more we learn, the more we know we don't know, and the more we must dedicate ourselves to learning and knowing more.

The CHAIRMAN. Thank you, sir.

Ms. Mariette DiChristina is Editor-in-Chief—this blows me away. You're the first woman to lead the 169-year-old *Scientific American* publication, which is the longest continuing publication in the United States of America. Am I right?

STATEMENT OF MARIETTE DiCHRISTINA, EDITOR-IN-CHIEF AND SENIOR VICE PRESIDENT, *SCIENTIFIC AMERICAN*

Ms. DiCHRISTINA. It is.

The CHAIRMAN. So you're on.

Ms. DiCHRISTINA. Thank you.

The CHAIRMAN. Don't forget to turn your——

Ms. DiCHRISTINA. For me to follow that—yes. It's not——

The CHAIRMAN. Yes. Good.

Ms. DiCHRISTINA. Thank you.

Thank you, Chairman Rockefeller, so much and Ranking Member Thune and the Committee for the honor and privilege of addressing you today about science.

The CHAIRMAN. Can you pull that a little bit closer?

Ms. DiCHRISTINA. A little closer?

The CHAIRMAN. Thank you.

Ms. DiCHRISTINA. How's this? Much better.

So yes, my name is Mariette DiChristina. I am the Editor-in-Chief of *Scientific American,* which has chronicled the power of U.S. research and innovation since 1845 when it was founded. *Scientific American* also founded the first branch for the U.S. patent agency in 1850. And among the visitors that came and visited the

[4] *https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm*

editor's offices was Thomas Edison. Albert Einstein wrote for *Scientific American* and so have more than 150 Noble laureates and many winners of the National Medals of Science and Technology.

It reaches more than 3.5 million viewers and readers in print and more than 6 million online. And the readers include leaders in business and policy, educators, students, and science enthusiasts the world over. From this, I'm giving you a professional observer's opinion about science.

Science is the engine of human prosperity. Economists have said, and it's been quoted many places, that a third to half U.S. economic growth has resulted from basic research since World War II; the cars and trains that got us here today. Think about it. The smart phones in our pockets, the energy that lights this chamber in this room, the clothes we wear, the food we eat: all of these things were developed and improved through basic research. But before these applications existed, researchers had to study the basic concepts that provided a sound underpinning, and they did those studies not necessarily knowing where they would lead.

I know Einstein, for instance, was not at all thinking about the GPS in our smart phones when he formulated the Theory of Relativity. But, in truth, knowing how space-time works helps us fix those measurements from the GPS satellites. And Elizabeth Blackburn told me that she was just curious about what was at the end of chromosomes when she started studying the DNA of pond scum in the 1970s. The NIH started funding her research in 1978. And in 2009, she and two fellow NIH grantees, Carol Greider and Jack Szostak, won a Nobel for their work in understanding what's at the end of those chromosomes, structures called telomeres which we now understand to play an important role in human cancers and other diseases of aging.

Examples like Elizabeth Blackburn show us why providing steady and sufficient support for basic research should be a national priority. We need to take the long view on R&D for the Nation's future just as we need to nurture our children over their entire K–12 academic careers just so they can succeed in an increasingly competitive global marketplace.

Research, like those children, takes time to do right. Typical funding grants take 5 years, are 5 years long and it takes time to run those experiments, gather the data, analyze it properly, and confirm those findings. But our own track record in the U.S. proves that steady Federal funding support leads to success. U.S. Federal funding was key to nearly 90 percent of almost 100 top innovations from 1971 to 2006 as identified by *R&D Magazine.*

Our nation's ability to handle today's most pressing issues, from providing energy security, let's say to curing illnesses, to living sustainably in a finite world will require the innovations that come from basic research.

It also does provide a good return. And a particularly strong example that people like to point out, the Human Genome Project paid back $141 per every dollar invested in it during the research period. In general, you should know that the return for publicly funded R&D is somewhere between 30 and 100 percent. That's a pretty strong return.

And from my perspective also, from the public's behalf, basic research can be really inspiring. Vint mentioned the Maker Movement which is such a phenomenon that the U.S. Office of Science and Technology Policy is actually holding Maker Faire events.

But, even beyond that, let me give you another example. The Zooniverse website, for instance, lets anybody catalogue heavenly objects made from NASA photographs. It has more than a million volunteers participating actively in science. Thousands of *Scientific American's* own volunteers catalogued more than 100,000 whale songs in just 2 months, which is the work of years in the lab.

Unfortunately, since the 1980s, R&D spending overall has flattened out a bit and even declined in real dollars. But I agree with you, Mr. Chairman, that we need patience and endurance for this. Because of the length of time needed for research also, the sequester cuts will effect progress for years to come in forestalled and canceled work, and it will disproportionately effect and discourage some of our younger researchers.

Meanwhile, countries such as China because, as you said, there is a choice to make, they're nipping at our heels. Earlier this year, in fact, China's rate of GDP investment just surpassed that of the 28 member-states of the European Union, and could exceed that of the U.S. itself in a little over half a decade, according to the 2014 Global R&D Forecast by *Battelle* and *R&D Magazine.* Japan, Denmark, Finland, Germany, Israel and Sweden already spend a greater percentage of their GDP on research than the U.S., according to World Bank.

The strong educational pipeline, as you pointed out, is also critical. Over the past 10 years, STEM jobs grew three times as fast as non-STEM, says the U.S. Department of Commerce. And our leading technology companies are often challenged in filling the necessary openings.

Last and in conclusion for one more view, I thought I'd ask a member of the next generation. I told my older daughter, Selina, who plans to double major in computer science and graphic design, yay, that I'd be speaking about this with you today, and I asked her what she would say about science. She said, "That's easy, mom, it's the foundation of everything."

And so it is. Science is a system for exploring and for innovation. It can fuel our Nation's economic growth. It can form a path for our young people in a competitive global marketplace and it can inspire and fire our imaginations. That's why basic research deserves a prominent place on the national agenda and our steady commitment in investment.

Thanks very much.

[The prepared statement of Ms. DiChristina follows:]

PREPARED STATEMENT OF MARIETTE DICHRISTINA, EDITOR-IN-CHIEF AND SENIOR VICE PRESIDENT, *SCIENTIFIC AMERICAN*

Thank you, honorable members of the Senate Subcommittee on Commerce, Science and Transportation, for the privilege of addressing you today about the importance of science and science education.

My name is Mariette DiChristina, and I'm the Editor-in-Chief and Senior Vice President of *Scientific American,* the oldest continuously published magazine in the United States. It was founded in 1845, during the Industrial Revolution in the U.S. To foster innovation, *Scientific American* started the first branch of the U.S. patent agency in 1850. Samuel Morse, inventor of the telegraph, and Elias Howe, inventor of the sewing machine, were among the scientists and inventors who visited the offices. Thomas Edison showed the editors his phonograph. It asked them: "How do you like the talking box?" Albert Einstein wrote an article for *Scientific American,* as have more than 150 Nobel laureates and many winners of the National Medals of Science and Technology given by the White House.

Despite its name, it's not a magazine aimed at scientists, although I'm pleased that some of them read it, too. Business leaders make up more than 50 percent of its audience of more than 3.5 million in print more than 6 million online—and nearly 20 percent are C-suite, looking to science for ways to grow their businesses. Of the 200 titles measured by MRI, it is number 6 for "Influentials." Educators, students, policy leaders and science enthusiasts read *Scientific American* for innovation insights.

At the same time, *Scientific American* has always had an educational mission to share the value and wonder of science. A subscription cost $2 a year in 1845, but in the first issue the editors promised it would be worth "five times its cost in school instruction." The magazine detailed the research and technologies that won World Wars I and II, the great space race that landed U.S. men on the moon 45 years ago yesterday, the rise of computer science and electronics that have today transformed our lives in the modern world, among other things.

Science is the engine of human prosperity. Economists have said that a third to a half of U.S. economic growth has resulted from basic research since World War II. The cars and trains that got us to this building, the smart phones we are all carrying, the energy we are using to run the lights in this chamber, the clothes we are wearing, the food we eat: All of these things were developed through the process that we call science. And before the conveniences that we enjoy today existed, researchers had to pioneer the basic concepts that provided a sound foundation for those applications—and they did that pioneering not necessarily knowing where it would lead. I know Einstein wasn't thinking about the conveniences we enjoy from GPS in our smart phones when he formulated his theory of relativity a hundred years ago, for instance. But knowing how spacetime works helps make our measurement from orbiting satellites accurate.

For all of these reasons, we need to make it a national priority to provide steady and sufficient support for basic research in science, and to STEM education and public outreach. We need to take the long view on R&D investment for the Nation's continued future well-being, just as we need to nurture, educate and inspire our children over their K–12 careers so that they can succeed in an increasingly competitive global marketplace.

Successful basic research takes careful work and patience. Typical funding grants are five years long. It takes time to run the experiments, gather the data, analyze it properly, and confirm the findings. Conducting basic research properly also means following human curiosity and exploring questions that may not have immediately obvious answers or applications.

But our own U.S. track record of Federal investment shows that there is an important relationship between steady investment in that R&D and our success in innovation and economic growth. U.S. Federal funding was key to nearly 90 percent of almost 100 top innovations from 1971 to 2006 identified by R&D Magazine, for example. Federal funding at DOE led to such innovations as the optical recording technology that lets us enjoy DVDs; the communications satellites that help us send information around the world, modern water-purification systems and supercomputers. NSF funding for a couple of students got us Google and also new technologies used in industries including biotech, advanced manufacturing and environmental resource management. DARPA's basic research led to GPS, the Internet, and Siri on iPhones. It's so easy to go on and on.

Our success in addressing many of the key issues that face the Nation today, from ensuring our energy security to providing healthy foods to medical advances to cure illnesses to our ability to live well and sustainably in a finite world, will turn on the innovations that arise from basic science research.

Basic research also provides a good direct return on investment. A report by research firm Battelle Technology Partnership Practice, for instance, estimates that between 1988 and 2010, Federal investment in genomic research generated an economic impact of $796 billion compared with $3.8 billion spent on the Genome Project between 1990–2003 amounted to $3.8 billion. That's an ROI of $141 for each dollar invested.

So today we are benefitting from past R&D investments. But our preeminence requires constant vigilance. The U.S. is still dominant in global research but our investments have flattened and declined in real dollars since the 1980s according to a report from the Congressional Budget Office on R&D and Productivity Growth.

Because of the length of time needed for basic research, also, the Sequester cuts will affect progress for years to come in forestalled and canceled work. Meanwhile, countries such as China are fast nipping at our heels. China's rate of GDP investment earlier this year surpassed that of the 28 member states of the European Union, and it is on track to exceed that of the U.S. itself in a little over half a decade, according to the 2014 Global R&D Forecast by Battelle and R&D Magazine. Japan, Denmark, Finland, Germany, Israel and Sweden already spend a greater percentage of their GDP on R&D than the U.S., according to World Bank. Germany's strategy to boost economic growth has been to increase investment, lifting its own Federal expenditures by 21 percent since 2005. These investments played an important role in Germany's 3.6 percent growth in 2010 compared with 2.9 percent growth rate in the U.S. during the same time period.

The STEM pipeline in education is also critically important to that economic well-being. Seventeen of 20 of the fastest growing jobs for the next decade are in STEM-related fields, and our leading technology companies are often challenged in trying to fill the necessary openings.

So basic research helps benefit our well-being, the Nation's economic growth, and the creation of jobs. It's also increasingly inspiring to the public who can now engage with it directly thanks to digital platforms. Although the headlines about celebrities don't show it, we know well at *Scientific American* how basic research has captured the public's imagination. Let's look the grass-roots level. We see two groundswells in participation by hundreds of thousands of people in enthusiasm around citizen science and the maker movement. Citizen scientists are people like you and me who can help scientists conduct basic research by making observations or in other ways. The Zooniverse Website, for instance, lets anybody catalog heavenly objects from NASA images. The Zooniverse has more than one million volunteer citizen scientists! *Scientific American's* own Whale.FM citizen-science project, which lets you match up snippets of whale songs, in two months catalogued more than 100,000 such calls—equal to a couple of years of work by lab researchers. Volunteers using the FoldIt protein-folding online game recently solved a puzzle that eluded HIV researchers for 15 years. And the Maker movement is such a phenomenon that the U.S. Office of Science & Technology Policy is holding Maker Faire events.

For one more viewpoint on the value of basic research, I thought I'd turn to a member of the next generation. I told my older daughter, Selina, who plans to double major in computer science and graphic design, that I would be speaking about this topic. I asked her what she would say about why science is important. How could I explain its importance, I asked her?

"That's easy, mom," she said to me. "It's the foundation of everything."

And so it is. Science is not a set of facts or received wisdom that's been handed down. It's a system for innovation and advancement—and humankind's best invention yet for pursuing the truth and an understanding of how the world works. It can fuel our economic growth as a nation, and form a path for our young people in a competitive global marketplace. And science can fire our imagination.

It can bring out the best in our Nation and in us. That's why basic-science research needs our steady commitment and investment. Thank you for your kind attention.

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The CHAIRMAN. Thank you very, very much.

And now we have Dr. Neal Lane. And I'm accustomed to you being in government not being a senior fellow somewhere. But, in any event, you're at the Technology Policy, Baker Institute for Public Policy; Malcolm Gillis University Professor and Professor of Physics and Astronomy at Rice University; Co-Chair of Committee on Models for U.S. Science and Technology Policy, American Academy of Arts & Sciences in Houston, Texas. So you're definitely geographic.

And we welcome you and we welcome your testimony.

STATEMENT OF NEAL LANE, SENIOR FELLOW IN SCIENCE AND TECHNOLOGY POLICY, BAKER INSTITUTE FOR PUBLIC POLICY, MALCOLM GILLIS UNIVERSITY PROFESSOR AND PROFESSOR OF PHYSICS AND ASTRONOMY, RICE UNIVERSITY; CO-CHAIR, COMMITTEE ON NEW MODELS FOR U.S. SCIENCE AND TECHNOLOGY POLICY, AMERICAN ACADEMY OF ARTS & SCIENCES

Dr. LANE. Thank you very much, Chairman Rockefeller, Ranking Member Thune. I'm delighted to be here. Thank you for holding this hearing, allowing me to join this distinguished panel.

I very much appreciate your comment about Senator Hutchison. I had the great pleasure of working with the Senator over the years; she's such a great, strong supporter of science, engineering, research in this country. She even started an academy for medicine, engineering, science and technology in Texas.

The CHAIRMAN. She did that?

Dr. LANE. She put that academy in place——

The CHAIRMAN. Interesting.

Dr. LANE.—and continues to support those activities, but she supports science across the country, of course, because she recognizes how important it is to the nation's future.

I would like to tell you a little bit about this project the American Academy of Arts and Sciences, a study group that I have the privilege to co-chair with Mr. Norm Augustine, a former CEO, retired CEO of Lockheed Martin and I think a person well-known to this committee. I want to emphasize my remarks are my own. They don't necessarily represent Rice or the Academy or the study group.

We have a bipartisan committee of leaders from all sectors exploring how to ensure America's leadership in science, engineering and technology, and the long-term sustainability of the research enterprise will be accomplished. We started with three premises. First, that a strong U.S. economy is vital to the welfare and prosperity of the American people.

Second, that in today's accelerating, high-tech, knowledge-based technology, staying competitive requires innovation and the rapid infusion of new knowledge and technologies coming out of R&D investments.

And third, that while the applied research and development are undeniably important, it's often that the path-breaking discoveries come out of basic research where one has no idea going in what the ultimate impact might be, and of course much of that basic research is funded by the Federal Government.

Ironically though, at a time when the rest of the world, particularly China and other Asian countries have adopted our model which has worked so well, we in the U.S. seem to have lost our passion to compete. Recent data showed that the U.S. has slipped to tenth place among OECD nations and overall R&D investment as a fraction of GDP. And it continues to fall short of the 3 percent goal that several presidents have put forward. China is projected to outspend the U.S. in R&D in less than 10 years in absolute terms and as a fraction of GDP, and my colleagues tell me—and this is most important in my view—many of my colleagues tell me that now the most important scientific papers in their fields, published in the most prestigious journals, are coming out of China.

Industries make clear, as Dr. Cerf has indicated, that the Federal Government will have to be the primary funder of basic research since companies cannot justify to their stockholders that Federal support for basic research is now below the level as a percentage of GDP as it was in 1990. The good news, I believe, is that Federal research investments have long been viewed by presidents and members of Congress from both parties as vital to the national interest.

Indeed, during the approximately 20-year period, 1975 to about 1992, Federal funding for basic research grew in inflation-adjusted dollars by over 4 percent per year; it's a remarkable sort of steady growth curve. But that was a time when all kinds of things were happening: we had a period of deep inflation; we had oil embargoes; we had back and forth between the leadership in both political parties. Nonetheless, Republicans and Democrats were able to agree that basic research should be a high priority for the nation.

If that growth curve had continued to today, the Federal funding of basic research would be over 33 percent higher than it is right now. Our committee's report, though, will focus on two overarching challenges, or objectives.

In order to ensure that the American people receive the maximum benefits from the Federal investments and research, we'll recommend three actions. First, increasing research productivity by streamlining unnecessarily burdensome Federal regulations and agency practices, also changing some university practices. Second, reaffirming the importance of Federal investments in research in all fields and the use of expert peer review managed by the agencies to select the very best people and ideas among competing ones. And third, increasing the flow of research discoveries to applications by encouraging universities to form stronger collaborations with industry.

The second objective complements the first. In order to secure America's leadership in science and engineering research, especially basic research by providing sustainable Federal investments, we will recommend establishing appropriate goals for sustainable growth in Federal basic research funding and making changes in the Federal budget process to allow long-term planning especially with regard to the capital cost of larger research facilities.

In addition, we will offer recommendations to all sectors to develop more robust research partnerships and drive American innovation throughout the twenty-first century. That is likely to require a level of cooperation and coordination that we have not seen in many decades, if ever, in this country.

The American Academy intends to release its report in early fall. I look forward to further discussions with the Committee.

Mr. Chairman, Ranking Member Thune, thank you so much for inviting me to participate in today's important hearing.

[The prepared statement of Dr. Lane follows:]

PREPARED STATEMENT OF NEAL LANE, MALCOLM GILLIS UNIVERSITY PROFESSOR, PROFESSOR OF PHYSICS AND ASTRONOMY, RICE UNIVERSITY; SENIOR FELLOW, RICE UNIVERSITY'S BAKER INSTITUTE FOR PUBLIC POLICY, ON BEHALF OF THE AMERICAN ACADEMY OF ARTS & SCIENCES COMMITTEE ON NEW MODELS FOR U.S. SCIENCE AND TECHNOLOGY POLICY

Chairman Rockefeller, Ranking Member Thune, and Members of the Committee: I am honored to be invited here today to discuss the Federal Government's investments in research. I am the Malcolm Gillis University Professor and Professor of Physics and Astronomy at Rice University, and also hold an appointment as the Senior Fellow in Science and Technology Policy at Rice University's Baker Institute for Public Policy. Prior to returning to Rice University, I served in the Federal Government during the Clinton Administration as Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology Policy, from August 1998 to January 2001, and as Director of the National Science Foundation (NSF) and member (*ex officio*) of the National Science Board, from October 1993 to August 1998.

I am also honored to be a Fellow of the American Academy of Arts and Sciences and to appear on its behalf today. Founded in 1780 by John Adams and other scholar-patriots to encourage dialogue among leaders of science, the arts, business and public affairs, the American Academy of Arts & Sciences is an independent policy research institute that engaged in the study of complex problems vital to our Nation's future. Through its projects and studies, and publications like its recent *ARISE I* and *ARISE II* (*Advancing Research in Science and Engineering*) reports, the Academy pursues practical policy responses to pressing national and global problems.

I am particularly honored to co-chair, with Norman R. Augustine, retired CEO and Chairman of Lockheed Martin Corporation, the American Academy's Committee on New Models for U.S. Science and Technology. This group has been working over the past year to develop recommendations of policy actions that we believe will help ensure the long-term sustainability of the U.S. science and engineering research enterprise. While my testimony today generally reflects the group's conclusions, I should state at the outset that my remarks represent my own views and not necessarily those of the study group, the American Academy, or Rice University.

The Role of Research in Sustaining Economic Prosperity

In a 1988 radio address to the nation, President Ronald Reagan said that "although basic research does not begin with a particular practical goal, when you look at the results over the years, it ends up being one of the most practical things government does . . . Major industries, including television, communications, and computer industries, couldn't be where they are today without developments that began with this basic research." Many presidents—Democrats and Republicans—have emphasized the importance of science, engineering and technology to the Nation's leadership in the world, the strength of its economy, and the welfare and prosperity of its people. And I want to emphasize that research, in this context, refers to all fields—the physical and life sciences (including medical research, mathematics, computer science, and engineering) and the social and behavioral sciences.

As President Reagan and other presidents have realized, virtually every new technology is traceable to a research discovery or series of discoveries, often made by individuals having no idea of how their research might help create jobs and benefit millions of people in other ways years or even decades in the future. To expect continued technological advancement, a strong economy, job growth and other public benefits without investing in research is akin to operating an automobile factory without a receiving dock for raw materials.

In short, new knowledge and technologies, which are the products of research, are the lifeblood of today's accelerating high-tech, knowledge-based economy. If the U.S. is to remain a leader in this new economy, it will have to ensure that it has a skilled workforce particularly in STEM (science, technology, engineering and mathematics) areas, and a robust science and engineering research enterprise that matches the challenge. It should be clear that both education and science and engineering research play a critical role in the economic and personal wellbeing of Americans in this "Land of Opportunity."

This is what we used to call the "American Dream." The American Dream is a national ethos whose foundation is rooted in opportunity: the opportunity for a quality job and career, a quality life, a quality education, and the opportunity for our children to achieve more and have a better life. It imbues the Nation with a spirit of hard-work and determination—if you study hard, work hard and play by the rules, you can have a good life. Late last year, we lost to cancer a great American and champion of science, engineering and education, Charles (Chuck) Vest, who grew up in West Virginia and became President of MIT and, more recently, served as President of the National Academy of Engineering. Chuck often spoke about having lived the American Dream. Growing up in the oil fields of Oklahoma, I have also lived the American Dream, and so did many of my generation. But we don't hear much about it anymore. America's expectations—and the hopes and dreams of Americans—seem less ambitious today, and that should scare us. Without opportunity, the American Dream fades, and with it a key part of our identity as a nation.

Ensuring opportunity for all Americans will require significant improvements in education and learning, especially in STEM areas, as well as a strong economy. With regard to economy, research has demonstrated a strong correlation between job growth and Gross Domestic Product (GDP)—creating jobs on a large scale requires growing the Nation's GDP. Numerous studies, including Robert Solow's Nobel Prize-winning research, have shown that the predominant driver of GDP growth over the past half-century has been scientific and technological advancement. It seems likely, given the current accelerating pace of progress in science, engineering and technology, that this observation will continue to hold for the decades ahead.

Yet too often the role of research, particularly basic research, in the Nation's scientific and technological advancement has been undervalued. Hunter Rawlings, the president of the American Association of Universities, has observed that the fundamental technologies that underlie today's remarkable consumer electronics, including GPS, multi-touch screens, LCD displays, lithium-ion batteries, and cellular networks, were all derived from research supported by the Federal Government and conducted in universities and government laboratories. Of course, America has led in these areas because it has a diversity of companies—large and small—which have been willing to take risks, try new innovative practices, invest in their own R&D needs, and take chances on new technologies. America also has an investment community willing to help fund these efforts and regulations to insure fair competition in the marketplace. But basic research, much of which is government-funded, is necessary to cultivate an ecosystem rich enough in new knowledge and ideas to enable these breakthrough achievements.

The power of America's economic system and the role its universities, industry and government have played in its effectiveness have not gone unnoticed by other countries competing in the global job market. In fact, they seek not only to copy it but to improve upon it. The influential National Academies' report *Rising Above the Gathering Storm* and its updates [1,2] make the case that instead of racing to meet the challenge, America instead is permitting this highly successful system of discovery and innovation, that has served this Nation well since the end of WWII, to atrophy. This is not a formula for success in a highly competitive world that is advancing at an accelerating rate.

The Role of the Federal Government

If science, engineering and technology are key drivers of economic growth, as the evidence strongly indicates, one metric of the adequacy of a nation's commitment to the future of its citizens is its total investment in R&D as a fraction of GDP, relative to competitor nations. The total U.S. investment (⅓ public and ⅔ private [3]) in R&D continues to fall short of the national goal adopted by several U.S. presidents of 3 percent of GDP, even as America's economic competitors move aggressively to increase their own investments. The U.S. has fallen to 10th place among OECD countries (Figure 1). For example, China's R&D investment is growing at an average annual rate of 8 percent above inflation, and is on a path to overtake the U.S. in just 8 years. America is failing to make the R&D investments that are necessary to remain a global leader in industry and commerce.

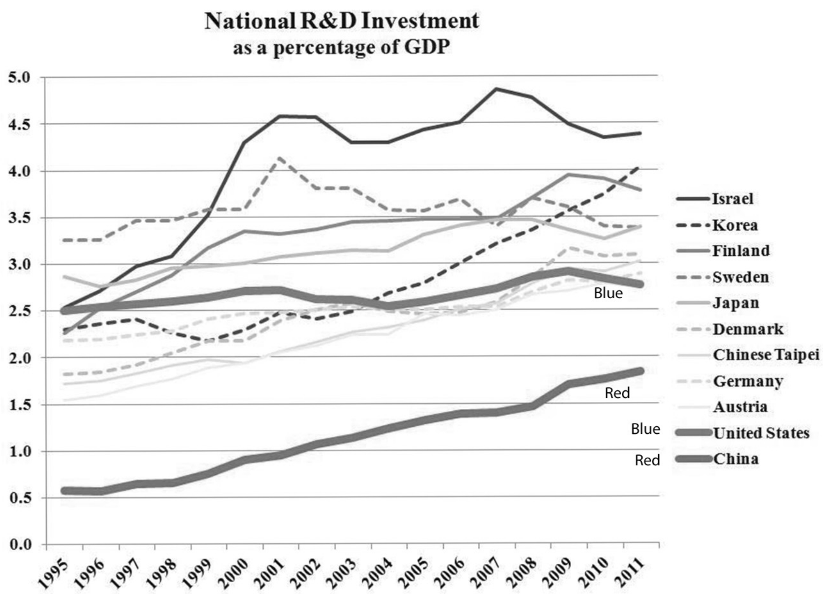

Figure 1. The U.S. is failing to keep pace with competitors' investments in R&D.

Among OECD nations, the U.S. ranks 10th in national R&D investment as a percentage of GDP, or R&D intensity. As China's R&D intensity (red line) rapidly grows at an average of 8 percent per year in pursuit of the globally-recognized 3 percent GDP goal, U.S. investments (blue line) have pulled back. At this pace, China will surpass the U.S. by this measure in about eight years.

Data Source: OECD, Main Science and Technology Indicators, 2013, Gross Domestic Expenditures on R&D as a percentage of GDP. Available at: http://stats.oecd.org/.

These disturbing trends have created a gap between what America *is* investing and what it *should be* investing to reclaim our global competitiveness and ensure

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[1] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.* (Washington, D.C.: The National Academies Press, 2007).

[2] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5.* (Washington, D.C.: The National Academies Press, 2010).

[3] Although industry funds 2/3 of total U.S. R&D, it is worth noting that the vast majority of this funding (95 percent) is devoted to applied research and development. Over half of all basic research is funded by the Federal Government (55 percent of total national basic research funding).

a strong future economy. This has been described as running an "innovation deficit"[4]

To be sure, most of America's innovation and high-quality jobs are created in private industry. But companies depend on a continuous stream of new scientific discoveries and early-stage technologies that flow from the Federal Government's investments in research, particularly basic research, carried out at research universities and national laboratories. Companies working closely with academic and government researchers benefit most from timely translation of research results into marketable applications and from early access to talented scientists and engineers trained largely at American universities.

Some may ask why America shouldn't just let other nations pay for the research and then simply apply the resulting discoveries to grow markets and create jobs within our own borders. That approach may have worked for other nations in the past, but it is not a winning strategy for the future. Given the pace at which technological innovation is accelerating today, being second to market is now considered by many executives to be tantamount to failure. Craig Barrett, the retired CEO of Intel, has noted that 90 percent of the revenues that firm receives at the end of its Fiscal Year are derived from products that did not even exist at the beginning of that year.[5] Such a system would not work without a rich base of knowledge and discoveries and strong links to industry.

Some have expressed the hope that the decline in the Federal investment in research could be compensated by increased investments in other sectors. This hope is almost certainly in vain: companies are increasingly concentrated on applied research and development, arguing that they cannot justify spending money on basic research which could benefit other companies, public research universities are in no position to substantially increase research investments due to declining state support; and philanthropic organizations and individuals, while an important and growing source of support for American science, still contribute a small portion of the national research investment. Foundations spend about $2 billion annually on basic research.[6] While this is a substantial contribution, it represents less than 3 percent of total national spending on basic research.[7]

This leaves the Federal Government as the primary supporter of fundamental research for the foreseeable future. Thus, the recent decline in the Federal investment in basic research has left the U.S. in danger of being overtaken by other nations that are rapidly advancing in science, engineering and technology.

Two goals must be met in order to reverse this trend. First, we must ensure that the American people receive maximum benefits from Federal investments in research, in part by strengthening partnerships across governments, universities, and industry and business. Second, we must develop a sustainable approach to research funding.

These two goals have guided the work of the American Academy committee that I have the privilege to co-chair with Norman R. Augustine. I will briefly discuss what our 23 eminent colleagues, who include Nobel laureates, corporate executives, university presidents and deans, and other leaders in science and engineering,[8] have determined must be done in the near future to achieve these goals.

Ensuring that the American People Receive Maximum Benefits from Federal Investments in Research

As I have argued earlier, Federal research investments are vital to America's leadership in SE&T. But many current policies and practices in government, industry and universities hinder the most effective use of those investments. Given the accelerating pace of technological advancement in many parts of the world, particularly in Asia, a rapid response is needed. Policy changes in all sectors are necessary to accelerate the discovery of new knowledge and the translation of new insights and tools into technological innovation to ensure that the American people enjoy the benefits of their investment in research.

First, we must streamline those regulations and practices governing federally-funded research that add to universities' administrative overhead while yielding

[4] See *http://www.innovationdeficit.org/*.

[5] N.R. Augustine, *Is America Falling Off the Flat Earth?* (Washington, D.C.: The National Academies Press, 2007).

[6] Based upon estimates from the Foundation Center: "Distribution of Foundation Grants by Subject Categories, circa 2011" in the categories of "Medical Research" and "Science and Technology". See *http://foundationcenter.org/findfunders/statistics/pdf/04_fund_sub/2011/10_11.pdf.*

[7] Fiona Murray, "Evaluating the Role of Science Philanthropy in American Research Universities," *Innovation Policy and the Economy,* 13 (2013):1–40.

[8] *www.amacad.org/newmodels*

questionable benefits. No more cost-effective step could be taken to increase the productivity of America's researchers, particularly those based at universities. Unquestionably, the Federal Government has an obligation to ensure that the money it provides to universities to support research on their campuses is used for the intended purposes and that research practices are held to high standards of performance—thus, regulations and administrative policies are necessary. However, many regulations and business practices are ineffective, vary from agency to agency across the Federal Government, and constitute unnecessary and costly burdens to researchers and their institutions that have the unintended consequences of reducing research productivity and forcing the institutions to use their own funds to cover the portion of research administrative costs not funded by the agencies. The full set of relevant regulations and practices should be examined with the objective of maximizing the effectiveness of the Federal research investment.[9]

Second, all parties must work together to uphold America's unparalleled system of expert peer review. Competitive expert peer review is the best way to assure excellence. Hence, peer review should remain the mechanism used by Federal agencies to make research award decisions, and review processes and criteria should be left to the discretion of the agencies themselves. In the case of basic research, scientific merit, based on the opinions of experts in the field, should remain the primary consideration for awarding support. This system has been used, successfully, for well over half a century. No better system has been devised, particularly for basic research where the likely outcome cannot be predicted.

Third, the public benefits of Federal research investments can be more readily realized by establishing a more robust national government-university-industry research partnership. Other countries recognize this need and are taking active steps to put such national research partnerships in place. Yet in the U.S., the accumulation of decades of policies and practices in each sector, as well as shifting priorities of the states and unpredictable Federal research funding levels, are allowing our Nation to slip steadily behind.

The Bayh-Dole Act (Patent and Trademark Law Amendment Act), signed into law in 1980, allows universities, small businesses and not-for-profit organizations to pursue ownership of an invention arising from federally funded research, subject to a number of conditions. This landmark legislation has been highly effective in getting IP into the hands of companies that can develop products from the technology and move them to market, and has enabled a small number of universities to derive substantial income from licensing. However, the majority of universities have found that the cost of maintaining a technology transfer office, filing for patents, and negotiating IP licensing exceeds the income generated from licensing. Licensing negotiations with companies can also pose a high barrier to collaboration, often delaying or preventing the transfer of technologies to a company and, potentially, a market. These realities have spurred many universities to reconsider the value of IP ownership. Some universities are experimenting with new policies to enhance the transfer of IP to the market and are implementing novel technology transfer practices in line with this policy. More universities should pioneer such experiments, the outcomes of which should be evaluated to derive best practices. And as universities choose to adopt more flexible approaches to handling IP, companies should explore forming stronger research partnerships with universities for mutual benefit.

University and corporate leadership and cooperation will be the key to advancing these reforms; and the professional science and engineering societies will continue to play an important role by keeping their members informed about best practices. The Federal Government should encourage universities to explore steps in this direction, including experimenting with innovative models for technology transfer, enhancing early exposure of students (including doctoral students) to a broad range of non-research career options, and increasing the interactions of university researchers with industry.

The result can be a richer, more innovative research environment that benefits all participants. The opportunity for strengthening the university-industry partnership has never been better.

Making the R&E (Research and Experimentation) tax credit permanent, as recommended by the National Academies, the American Academy, the Business Roundtable, the President's Council of Advisors on Science and Technology (PCAST), and many others, would provide an incentive for industry to invest in long-term research, including collaborative research with universities. Not doing so significantly reduces the potential benefits that federally supported academic research can pro-

[9] See, for example, the March 2014 National Science Board report, *Reducing Investigators' Administrative Workload for Federally Funded Research.*

vide to American taxpayers. That fact should override any arguments for the status quo.

Another recommendation that has been made by many other organizations, including PCAST[10] and the National Academies,[11,12] is to increase the number of H–1B visas and reshape policies affecting foreign-born researchers. Graduate students from around the globe seek an advanced education at American research universities, not only for the quality of training they receive but to advance their careers. For these reasons and others, most of these talented international students and researchers would stay in the U.S. if given the opportunity. However, international competition for talented scientists and engineers has grown fierce. If we fail to both attract *and retain* the best and brightest scientists and engineers, we risk not only steering American entrepreneurs overseas in their search for highly skilled workers, but further exacerbating the current shortage of educated workers that fuel American R&D and high-tech manufacturing sectors.

Securing America's Leadership in Science and Engineering Research—Especially Basic Research—by Providing Sustainable Federal Investments

Reestablishing America's competitiveness as a nation will require that federally funded research, particularly basic research, become a higher priority than has been the case in over two decades. In emphasizing basic research, I am not suggesting that the Federal role in supporting applied research and development are unimportant—such activities support the missions of many Federal agencies. But basic research is often where the breakthroughs occur that change paradigms and revolutionize technologies. The research efforts that led to the invention of the transistor and laser were not the result of trying to design a better vacuum tube or light bulb.

During the 18 years from 1975 to 1992, the Federal investment in basic research grew at an average annual inflation-adjusted rate of over 4 percent, despite serious challenges including the 1973 oil embargo, the Great Inflation of 1979–1982, and the final tumultuous years of the Cold War. Leaders in both parties, in the White House and Congress, were able to agree that investments in research should be a particularly high priority for Federal support. In recent years, however, the Nation's research funding has stagnated. As a function of U.S. economic output, Federal support for basic research is actually *lower* than it was twenty years ago.

While I recognize the difficulty of significantly growing Federal research funding in a period of fiscal constraint, it would be difficult to overstate the urgency of once again putting research funding on a sustainable growth path. Investments in basic research are just that: *investments.* America's economic ascendency in the 20th century was due in large part—perhaps even primarily—to its investments in science and engineering research. Basic research lies behind every new product brought to market, every new medical device or drug, every new defense and space technology, and many innovative business practices. Given the accelerating pace of technological advancement in many parts of the world, particularly in Asia, it follows that the U.S. must accelerate both discovery of new scientific knowledge and translation of that knowledge to useful purpose.

Simply put, if the U.S. is to remain a leader in providing these benefits, the Federal Government must make the necessary investments. Failure to act now may put us in a position from which we cannot recover, given the fast pace of global scientific advancement.

Conclusion

The American Academy report, to be released in early fall, will outline a series of specific actions that could be taken immediately to achieve the goals I have described. I look forward to sharing our ideas with this Committee. Real progress will depend on the extent to which the public and private sectors can cooperate effectively in support of a coherent national roadmap to strengthen the U.S. research enterprise, and to drive American innovation throughout the 21st century. As the President observed in this year's State of the Union address, "We know that the Nation that goes all-in on innovation today will own the global economy tomorrow. This is an edge America cannot surrender."

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[10] President's Council of Advisors on Science and Technology, *Transformation and Opportunity: The Future of the U.S. Research Enterprise,* 2012.

[11] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.* (Washington, D.C.: The National Academies Press, 2007).

[12] National Research Council. *Research Universities and the Future of America: Ten Breakthrough Actions Vital to Our Nation's Prosperity and Security.* (Washington, D.C.: The National Academies Press, 2012).

I look forward to your questions. Thank you again for the invitation to appear today.

BIOGRAPHY

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Dr. Neal Lane is the Malcolm Gillis University Professor and Professor of Physics and Astronomy at Rice University in Houston, Texas. He also holds an appointment as Senior Fellow in Science and Technology Policy at Rice University's Baker Institute for Public Policy.

Prior to returning to Rice University, Dr. Lane served in the Federal Government during the Clinton Administration as Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology Policy, from August 1998 to January 2001, and as Director of the National Science Foundation (NSF) and member (ex officio) of the National Science Board, from October 1993 to August 1998.

Before becoming the NSF Director, Dr. Lane was Provost and Professor of Physics at Rice University in Houston, Texas, a position he had held since 1986. He first came to Rice in 1966, when he joined the Department of Physics as an assistant professor. In 1972, he became Professor of Physics and Space Physics and Astronomy. He left Rice from mid-1984 to 1986 to serve as Chancellor of the University of Colorado at Colorado Springs. In addition, from 1979 to 1980, while on leave from Rice, he worked at the NSF as Director of the Division of Physics.

Widely regarded as a distinguished scientist and educator, Dr. Lane's many writings and presentations include topics in theoretical atomic and molecular physics and science and technology policy. Early in his career he received the W. Alton Jones Graduate Fellowship and held an NSF Doctoral Fellowship (University of Oklahoma), an NSF Post-Doctoral Fellowship (while in residence at Queen's University, Belfast, Northern Ireland) and an Alfred P. Sloan Foundation Fellowship (at Rice University and on research leave at Oxford University). He earned Phi Beta Kappa honors in 1960 and was inducted into Sigma Xi National Research Society in 1964, serving as its national president in 1993. He served as Visiting Fellow at the Joint Institute for Laboratory Astrophysics in 1965–66 and 1975–76. While a Professor at Rice, he was two-time recipient of the University's George R. Brown Prize for Superior Teaching.

Through his work with scientific and professional organizations and his participation on review and advisory committees for Federal and state agencies, Dr. Lane has contributed to public service throughout his career. He is a fellow of the American Physical Society, the American Academy of Arts and Sciences (member of its governing council), the American Association for Advancement of Science, and the Association for Women in Science. He serves on several boards and advisory committees.

Dr. Lane has received numerous prizes, awards, including the AAAS Philip Hauge Abelson Award, AAAS William D. Carey Award, American Society of Mechanical Engineers President's Award, American Chemical Society Public Service Award, American Astronomical Society/American Mathematical Society/American Physical Society Public Service Award, NASA Distinguished Service Award, Council of Science Societies Presidents Support of Science Award, Distinguished Alumni Award of the University of Oklahoma, and over a dozen honorary degrees. In 2009, Dr. Lane received the National Academy of Sciences Public Welfare Medal, the American Institute of Physics K.T. Compton Medal for Leadership in Physics, and the Association of Rice Alumni Gold Medal for service to Rice University.

Born in Oklahoma City in 1938, Dr. Lane earned his B.S., M.S., and Ph.D. (1964) degrees in physics from the University of Oklahoma. His thesis advisor was Chun

C. Lin (now at the University of Wisconsin—Madison). He is married to Joni Sue (Williams) Lane and has two children, Christy Saydjari and John Lane, and four grandchildren, Allia and Alex Saydjari, and Matthew and Jessica Lane.

The CHAIRMAN. Thank you, sir, very much.

Dr. Stephen Fienberg, the Maurice Falk University Professor of Statistics and Social—you're a neighbor; right? To West Virginia University?

Dr. FIENBERG. Indeed, sir.

The CHAIRMAN. And, in fact, we collaborate; do we not?

Carnegie Mellon is in that, University of Pittsburgh. I mean there's a nice collaboration.

Anyway, Professor of Statistics and Social Science, Department of Statistics, the Machine Learning Department, the Heinz College of, I can't pronounce it, Cylab, Carnegie Mellon University of Pittsburgh, Pennsylvania.

Can I just say that, as I'm looking at the four of you, I'm very much missing Chuck Vest. He came before this committee many times. Sometimes uninvited. He just invited himself——

[Laughter.]

The CHAIRMAN.—because he wanted us to understand all of the things that you're talking about. And he was absolutely militant about it. He was head of MIT for 13 years; the Department of Engineering for a long time. You know, he is just an absolutely marvelous human being and I miss him very much. Just listening——

Dr. FIENBERG. So do we all.

The CHAIRMAN.—all of you.

Please, sir.

STATEMENT OF STEPHEN FIENBERG, MAURICE FALK UNIVERSITY PROFESSOR OF STATISTICS AND SOCIAL SCIENCE, DEPARTMENT OF STATISTICS, THE MACHINE LEARNING DEPARTMENT, THE HEINZ COLLEGE, AND CYLAB, CARNEGIE MELLON UNIVERSITY

Dr. FIENBERG. Good afternoon, Mr. Chairman and Ranking Member, Senator Thune.

I was a member of the National Academy's committee on assessing the value of research in advancing national goals, and that was established with funds from NSF pursuant to the American COMPETES Act. Today, I'll share with you highlights from our report *Furthering America's Research Enterprise* which we have shared with you and the staff of the Committee. I, too, miss Chuck Vest. He was a dear friend and he worked hard with the Committee to help us focus on our task.

The question before us is: How can we effectively and efficiently enhance the benefits of scientific research and keep the Nation at the forefront of global competition for new technologies and innovations? In seeking answers, Congress and in particular this committee asked the academies to study measures of the impacts of research on society.

Some measures of research outputs give useful indications of how well the system is performing. But they can't depict the complex interconnected systems of research in innovation and the highly non-linear pathways that lead from research to technologies and other innovations. We found that the current measures are inadequate to guide national decisions about what research investments will expand the benefits of science. Moreover, we noted that the U.S. lacks in institutionalized capacity for systematically evaluating the Nation's research enterprise, taken as a whole, in assessing its performance developing policy options for federally-funded research.

Nevertheless, our committee concluded that the American research enterprise is indeed capable of producing increased benefits for U.S. society. To reap those benefits, however, we need to understand what's made our research enterprise so extraordinarily productive. It is because it reflects the character of American free enterprise. It's decentralized, pluralistic, competitive and meritocratic. And finally, it's entrepreneurial; encouraging risk taking.

To increase the benefits of research, the Federal Government must focus less on commercialization of research discoveries and certainly not on predicting the scientific fields that would lead to it that is predicting the winners. Rather, just as for business, government must focus on policies that promote the conditions for the research enterprise to thrive, what we, in our report, label as three crucial pillars. The first is a talented interconnected workforce developed through education and research training. Talent also comes from highly skilled immigrants, partnerships, support of research environments and worldwide scientific networks.

Adequate and dependable resources constitute the second pillar. Stable, flexible and predictable Federal funding encourages talented students to pursue scientific careers. It keeps established researchers engaged. It attracts and retains foreign talent. And it inspires the pursuit of riskier and more innovative research.

The third pillar is world-class basic research in all areas of science. Basic research pursued primarily to increase understanding and not necessarily toward a technological goal, provides the foundation of discovery and knowledge for economically significant innovations in the future.

These pillars interact. In the Department of Statistics at Carnegie Mellon, we employ and train our Ph.D. students with Federal and other support for basic research. But that support also creates a research environment in which we engage, stimulate and train many undergraduates and Masters Students. Those students represent the future of our scientific workforce.

World class basic research in all major areas of science is important because truly transformative scientific discoveries increasingly depend on research in a variety of fields. The development of the Google Page-Rank algorithm illustrates this especially well. In its 1997 patent application for the algorithm, it acknowledged support from NSF. It drew heavily on multiple discoveries spending nearly 45 years of social and information science research, and it included decades-old research on methods to determine social status and to study social networks.

We do indeed need to improve our measures of research activities, including outputs and technology transfer. But greater benefit will come from measures that guide the pillars of the research enterprise. If we cultivate talent, provide adequate and dependable resources, and invest in the diversity of basic research, fresh discoveries will continue to power our economy, and to enrich our lives in unpredictable and unimaginable ways.

Thank you.

[The prepared statement of Dr. Fienberg follows:]

PREPARED STATEMENT OF STEPHEN E. FIENBERG, MAURICE FALK UNIVERSITY PROFESSOR OF STATISTICS AND SOCIAL SCIENCE, CARNEGIE MELLON UNIVERSITY, PITTSBURGH, PA AND MEMBER, COMMITTEE ON ASSESSING THE VALUE OF RESEARCH IN ADVANCING NATIONAL GOALS, DIVISION ON BEHAVIORAL AND SOCIAL SCIENCES AND EDUCATION, NATIONAL RESEARCH COUNCIL, THE NATIONAL ACADEMIES

Good afternoon, Mr. Chairman and members of the Committee. My name is Stephen Fienberg. I am Maurice Falk University Professor of Statistics and Social Science at the Carnegie Mellon University with appointments in the Department of Statistics, the Heinz College, and the Department of Machine Learning, and I served as a member of the Committee on Assessing the Value of Research in Advancing National Goals of the National Research Council. The National Research Council is the operating arm of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine of the National Academies, chartered by Congress in 1863 to advise the government on matters of science and technology. The Committee was established with funding from the National Science Foundation pursuant to Section 521 of the America COMPETES Act of 2011. Today I will share with your Committee some of the highlights of our report, *Furthering America's Research Enterprise,* and I append to my remarks a list of members of the study committee and the Table of Contents of the report.

The context

The benefits of the Federal investment in scientific research are manifest and have enabled the United States to achieve unprecedented prosperity, security, and quality of life. But the Nation now faces increased global competition for new technologies and other innovations, in the face of growing economic exigencies. Congress wants to enhance the benefits of scientific research for the U.S. economy and other purposes and to keep the Nation at the forefront of global competition for new technologies and other innovations.

How can that be done effectively and efficiently? In particular, how can we increase the returns on current Federal investments in scientific research? In seeking answers to those questions, Congress asked the Academies to study measures of the impacts of research on society, especially those that could serve to increase the translation of research into commercial products and services. Also of interest was the use of such measures for purposes of accountability. The purview of the study was all federally supported research.

The Committee's Findings

I. Current measures are inadequate

While some measures of research outputs and benefits are useful for specific purposes, the Committee found that *current measures are inadequate to guide national decisions about what research investments will expand the benefits of science.*

The problem is that metrics used to assess any one aspect of the research system in isolation, without a strong understanding of the larger picture, may prove misleading. The benefits of research investments tend to arrive unpredictably, vary widely in eventual value, and require substantial additional investment (as well as investment in other fields of science) to realize their economic payoff through innovation. With few exceptions, approaches to measure the impacts and quality of research programs cannot depict the diffuse, interconnected and highly non-linear pathways that lead from research to technologies and other innovations. The widespread adoption of the innovation is a process that itself requires investment and substantial know-how.

Existing metrics give some indication of how well the system is performing, but the ultimate impacts, the emergent phenomena that truly matter to society such as an abundant supply of natural gas enabled by fracking technology, communications and commerce enabled by Google and the Internet, and medical advances enabled by genomics depend on a number of critical components, and the relationships among them, in the complex systems of research and innovation. These components often are intangible, including opportunities and relationships that are not captured by most data collection programs and cannot be measured by currently available methods.

II. Reaping further benefits

The committee concluded that the American research enterprise is indeed capable of producing increased benefits for U.S. society, as well as for the global community. To reap those benefits, however, we first need to understand what has made the American research enterprise so successful: what drives it and why has it been so productive.

Our research enterprise has been so successful because it has evolved as a complex, dynamic system with many of the characteristics of American free enterprise. It is decentralized. It is pluralistic, driven by a diverse array of researchers, companies, institutions, and funding agencies. *It is competitive,* requiring researchers and organizations to compete for funding, for talent, for positions, for publications, and for other rewards. *It is meritocratic,* bestowing more significant rewards on those with highly competitive ideas and abilities through a built-in quality control system of peer review. *And finally, it is entrepreneurial:* it allows for risk taking, for facing the prospect of failure head on to reap potentially great rewards.

Just as business thrives in free enterprise for its products and services, so too does our extraordinarily productive research enterprise for its ideas and discoveries.

As our assessment progressed it became clear to us *that increasing the benefits from the Federal investment in research depends far less on Federal promotion of the commercialization of research* discoveries *or* on *trying to predict the scientific fields that are most likely to lead to commercial products and services, than on Federal policies that promote the conditions for the research enterprise to thrive. We identified three crucial pillars of the research enterprise:*

1. *A talented and interconnected workforce.* The importance of talent cannot be overstated, both as input and as output. Talent benefits not only from public investments in traditional education and research training in science and engineering but also from highly skilled immigrants; partnerships; supportive research environments; and worldwide networks through which researchers connect with others, develop professional relationships and share ideas and scientific resources.
2. *Adequate and dependable resources.* Stable and predictable Federal funding encourages talented students to pursue scientific careers, keeps established researchers engaged over a career, and attracts and retains foreign talent. It also supports a diversity of institutions that both fund and conduct research, as well as essential scientific infrastructure–the tools necessary for conducting research. Flexibility and stability in funding, along with a culture that tolerates failure, may inspire researchers to pursue riskier and more innovative research with a greater chance of failure but also a greater likelihood of transformative impact. These resources are increasingly important to future U.S. competitiveness, given the rising investments in research by other countries, particularly China and other Asian nations.
3. *World-class basic research in all major areas of science.* Basic research, in which investigators pursue their ideas primarily for increased understanding and not necessarily toward a technological goal, often provides the foundation of discovery and knowledge for future economically significant innovations. Federal investments in basic research contribute to the growth of a trained research workforce, support the scientific infrastructure to conduct research, and enable U.S. researchers and would-be innovators to exploit the world-wide networks of researchers, who open access to a vast stock of knowledge and technological approaches. Absent a strong pool of scientists and engineers familiar with basic research at the cutting edge, scientific research and its products are unlikely to be developed and applied in ways that create value for society.

World-class basic research in ***all*** *major areas of science is important because truly transformative scientific discoveries increasingly depend on research in a variety of fields.* Moreover, in today's highly connected world, *a discovery made somewhere is soon known everywhere. The competitive advantage may go not to the Nation in which the discovery was made but to the Nation that can use it more effectively to develop new technologies and other innovations* by relying on a broad foundation of knowledge, talent, and capacity derived from basic research in a diversity of scientific fields. *Finally, a world-class basic research enterprise attracts scholars from around the world who further enhance excellence in research* and create a self-reinforcing cycle.

The development of Google is a good example of why a diversity of basic research is important. Google owes its remarkable success in part to its algorithm for ranking Web pages. The 1997 patent application for the algorithm, which acknowledged support from the National Science Foundation (NSF), drew heavily on multiple discoveries spanning nearly 45 years of social and information sciences research—discoveries made possible by funding from four Federal science agencies and protected by a handful of seemingly unrelated patents awarded to a university (Carnegie Mellon), corporations (Lucent, Libertech, AT&T, Matsushita), and industrial laboratories (AT&T Bell Labs). Critical to the development of the algorithm was decades-old research on methods to determine social status, and social network research from the 1970s. The development of the Google algorithm illustrates the importance of seemingly unrelated social science research; the convergence of research at universities, corporations, and industrial laboratories; and the unpredictable benefits of federally-funded research. Moreover, the economic model for Google advertising utilizes a variant of the Vickrey auction, first described in a 1961 theoretical economics paper and later developed by many others with NSF support. Other Internet-based companies have followed suit.

New as well as existing measures could be used to assess each of the three pillars. Such measures might include, for example, indicators of human and knowledge capital, indicators of the flow of knowledge in specific fields of science, indicators with which to track the flow of foreign research talent, portfolio analyses of Federal research investments by field of science, international benchmarking of research performance, and measures of research reproducibility. Another recent National Research Council report, *Capturing Change in Science, Technology, and Innovation: Improving Indicators to Inform Policy,* identified many measures for assessing the performance of policies intended to strengthen the three pillars of the research system.

The levels, composition, and efficiency of federally funded research need to be adjusted to meet today's circumstances and we need better metrics to inform policy decisions about research. But t*he United States lacks an institutionalized capability for systematically evaluating the Nation's research enterprise as a whole, assessing its performance, and developing policy options for federally funded research.* An organization charged with such a responsibility would increase the demand for policy relevant data of high quality. Although NSF's National Center for Science and Engineering Statistics produces valuable data (*e.g., Science and Engineering Indicators*) that could be used in policy analysis, NSF's role differs from that of Federal policy analysis agencies or statistics agencies such as the Bureau of Economic Analysis or the Economic Research Service that conduct policy analysis.

One U.S. data collection program—STAR METRICS (Science and Technology for America's Reinvestment: Measuring the Effect of Research on Innovation, Competitiveness and Science)—is designed to collect a number of measures of the impacts of federally funded research. This data program is a joint effort of multiple science agencies (the White House Office of Science and Technology Policy, NIH, NSF, the Department of Energy, and the Environmental Protection Agency) and research institutions. While STAR METRICS aims to document the outcomes and public benefits of national investments in science and engineering research for employment, knowledge generation, and health, our assessment is that it is not ready for prime time use.

STAR METRICS could potentially be of great value in assessing the value of research if efforts were made to (1) broaden coverage by enrolling additional institutions, (2) deepen coverage by expanding the data elements reported, (3) link the data to other national and international datasets, (4) establish the quality of the data, and, most importantly, (5) ensure broad, easy access for researchers. Such expanded data and access need to be coupled with modern analytical tools, such as complex network modeling and analysis. Our report provides a simple illustrative example, but with better data, such tools might reveal important interactions among components of the research enterprise using an expanded and restructured STAR METRICS program.

Enhancing America's research enterprise requires a better understanding not just of the three pillars of talent, resources, and basic research, but also of the relationships and interactions among them. For example, resources for basic research also provide for talent through the training of a research workforce and, by engaging undergraduate students in research, as we do at my university, Carnegie Mellon.

Let me use my Department of Statistics as an illustration. My faculty colleagues and I have a diversity of research grants and contracts that employ and train our Ph.D. students. But this Federal and international research support also creates a research environment that allows us to engage and train many undergraduates and master's students, who go on to advance their research skills at other research universities in statistics and many quantitatively-related disciplines. And this pattern is replicated across the university, fostered in part by the interdisciplinary activities of my colleagues. These students represent the future of our scientific workforce.

Other measures, which can help to make the research enterprise more efficient and which can provide information to guide the allocation of research funds arise in evaluations. We address in our report the evaluation of research funding programs, of peer review, and the effects of different funding programs, such as the NIH Pioneer Awards, on research performance. Unfortunately, most attempts at evaluation do not address the fundamental question: What would have happened but for the research funding program? At a higher level, evaluation efforts rarely address questions such as: what alternate allocation of resources between programs might promote a healthier research enterprise? If evaluations are conducted at all, they are often added after the fact. Evaluation needs to be built into research funding programs from the outset to help avoid the unmeasurable biases associated with ad hoc retrospective evaluation. Moreover, few evaluation studies or approaches adopt randomized controlled field experiments that control for biases and input differences. We need to address these evaluation challenges.

Measures of research activities, outputs, and technology transfer are important, but we need to improve both the measures and the underlying data. Greater benefit will come from measures to guide the pillars of the research enterprise—talent, resources, and basic research. If we cultivate talent, provide adequate and dependable resources, and invest in a diversity of basic research, fresh discoveries will continue to power our economy and to enrich our lives in unpredictable and unimaginable ways.

ATTACHMENT

Furthering America's Research Enterprise

Committee on Assessing the Value of Research in Advancing National Goals

Richard F. Celeste, Ann Griswold, and Miron L. Straf, *Editors*

Division of Behavioral and Social Sciences and Education

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The CHAIRMAN. Thank you very, very much.

Lots of questions.

Dr. Cerf, your career is a very good encapsulation of how government-funded, basic research can lead to technological innovation that has far reaching consequences for our economy and our world. Now you have spent part of your career at some of our leading universities, conducting research and training students. You spend part of your career as a government researcher at DARPA and you have worked in the private sector at companies like IBM, MCI, and Google that have been able to build successful business models based on your previous work.

Can you explain why developing a breakthrough technology like the Internet is not possible without our network of public and private resources?

Dr. CERF. Thank you, Mr. Chairman, for that question. It's one of the most fascinating parts of my career which is alternating back and forth between the research environment and the private sector taking advantage of what's been learned thanks to research support.

Let me suggest two things. First of all, in the case of ARPA, my work at UCLA and then Stanford University was supported by the defense department; the Advanced Research Projects Agency. And, although I would characterize the work as applied more than basic research, hiding underneath a lot of what we did was the need to have good understanding of mathematical models of the behavior of the systems that we were building.

So, to give you an example, Dr. Leonard Kleinrock, at UCLA and formerly MIT, built mathematical models of the way in which computer networks would function and was able to make some predictions about how it would behave. And my job when I was at UCLA, doing the predecessor to the Internet, was to gather data from the way this network functioned and compare with his queuing models to see whether or not his predictions were accurate relative to what we could measure.

And the thing that's so important about this, and I thank you so much for asking this question, is that there was in fact a feedback loop because the model sometimes didn't correctly predict what would happen and it would make us go back and figure out how to change the model in order to get better predictions.

On the other hand, sometimes the model would predict that bad things would happen and we had to go back and figure: How do we stop that from happening in the actual implementation? So this wonderful yin and yang of research and modeling and analysis and actual implementation really reinforced this process. But it took some years to take advantage of all that. And I won't go on and on, on this point, but I can tell that almost in every case there's some fundamental theory that has to support the mechanical outcomes.

I can't resist telling you one other anecdote. At Stanford University, Larry Page and Sergey Brin, as graduate students, had funding from NSF to do some research on the ability to manage large amounts of data and to try to figure out how to organize it. And in order to test their idea, they had to have enough computing equipment to do what they wanted to do which is literally download the entire worldwide web and index it.

Now I'm fond of going around telling everyone that permissionless innovation is really important. You shouldn't have to get permission to invent something. Well, I hadn't understood that this phase applied to what Larry and Sergey did, because I understand now that since they didn't have access to all the computing equipment they needed, they borrowed some. And I now understand that they didn't always have permission to borrow it. And yet, we now see permission-less innovation producing an extraordinary outcome; the success of Google.

The short story, sir, is that no successful implementation, no successful engineering, no successful business ever gets anywhere if there isn't a fundamental foundation below it that makes it work. And that's why understanding how the world works is so important.

The CHAIRMAN. Thank you and I turn to Senator Thune.

Senator THUNE. Thank you, Mr. Chairman.

Dr. Fienberg is a statistician and member of the National Research Council's Committee on Assessing the Value in Advancing National Goals. You identified new and existing measures to assess basic research, workforce, talent and resource. According to your report, such measures might include portfolio analyses of Federal research investments by each field of science, indicators to track the flow of foreign research talent, and international benchmarking of research performance.

The question is: how well, if at all, is the United States currently utilizing these measures and how could better assessment in these areas guide Federal policies regarding which research investments best expand the benefits of science?

Dr. FIENBERG. That's a complex question. Let me try to answer it in pieces. The place where we have metrics or measures at the moment, that seem to be doing pretty well, is in performance. We can count outputs. We count how many papers scientists publish; patents, publications and journals. So there we measure pretty well.

Evaluation measures tell us how research programs compare in terms of ultimate outcomes that benefit society, and it was really here where we saw much room for improvements. We looked across the board, at both what the U.S. measures now including the kinds of data gathered by the agency within NSF but more broadly, and then we asked what other countries were doing and how they were trying to gage their own research enterprises. And we found an astonishing lack of tools for that kind of assessment, especially at the program level where you want to ask how a program as a whole is doing as opposed to how an individual scientist or a subset of projects do. And that's an area where we actually need to invest in new research if we're going to get those kinds of performance and evaluation measures in hand to help you and the policymakers in Congress actually be able to assess the kinds of tradeoffs.

The three pillars that we identified, again talk about broad indicators, but even here there's much room for improvement. There is a program that was initiated by a number of Federal agencies called "STAR Metrics." And it was designed to give a unique look at these kinds of issues. We studied STAR Metrics in our committee deliberations, and we gave some illustrations of how those metrics might be used. But, what we concluded was that it wasn't ready for primetime. The data were insufficient. They weren't linked to other data that you would want to link it to for outputs, and the data weren't necessarily of high quality, and they weren't accessible by researchers who could provide the feedback to government agencies to make it work.

And so, I think that we have a long way to go to be able to really take stock of the real benefits and to be able to weigh decisions about different kinds of programs at a fairly high level.

Senator THUNE. Dr. Cerf, without a coordinated strategy the potential exists for multiple agencies with similar research funding to fund duplicative or overlapping research. What duplication have you witnessed or come across in your capacity at Google or as a member of the advisory boards for NSF and NIST, and can advisory bodies like those upon which you serve do more to review and oversee federally-funded research programs to ensure efficiency in the research enterprise?

Dr. CERF. So this is a really interesting question, Senator, because efficiency is not always manifest in the research enterprise. In fact, I must say, although I don't depend upon them, accidents are sometimes the most important sources of surprising and successful research.

I think you will remember the discovery of penicillin was preceded by a question of mold showing up in some petri dishes. And, around that mold, it appeared that no bacteria were growing. And Fleming, to his credit, instead of discarding this and saying "Well, there must be something wrong" said, "Hmm, that's funny." And it's the people who asked that question, that are the ones that end up with the Nobel prizes. So this is not to argue, however, that we can't be more deeply appreciative of how to fashion and how to decide research expenditures.

One way to do this is to take advantage of the scientific community's awareness of what we don't know. And one of the things that is so valuable about the peer review process is exactly that. When people make proposals, it is often to express things that we don't know. And the other is to review those processes and help us understand whether it's worth pursuing.

Nonetheless, I think I would like to aim my response partly at Dr. Fienberg's comments and ask a question about the way in which we evaluate research and its success. I've often wondered whether anyone has taken the time to look at a successful enterprise and ask the question: What led to that? You know, what is the tree of research results and maybe, you know, application results that have led us to this particular outcome? It's kind of like if you're an academic, you teach students and then some of them become academics and they teach students and then you have these academic grandchildren and great-grandchildren. I keep thinking that research results have a similar kind of character. Somebody gets a fundamental result and the question is: How did we take advantage of that knowledge?

So imagine lasers and eventually ending up with optical communications and CDs and DVDs and so on. I don't know if anyone—let me ask you. Am I allowed to ask the other guys questions?

[Laughter.]

Dr. CERF. Let me ask Dr. Fienberg.

Does anyone try to lay out the ancestry of these successful results? And if they don't, maybe we should because it would give us some insight about how this actually works.

Dr. FIENBERG. People actually do that, but there's an interesting side question. That is, that's a case study and people do such case studies in universities today. The more interesting question is: What would have happened if we hadn't funded the research program and it hadn't produced these outcomes? Where would American society be? Where would American industry be? And that counterfactual question is a much harder one to ask and answer, and it's one for which we have very poor tools to assess the outcome.

Senator THUNE. Mr. Chairman, I think their questions of each other may be better than mine. I don't think they're really necessary to this hearing but I'm glad that the Senator from Massachusetts has arrived.

Let me just ask, because you mentioned, Dr. Fienberg, and as the National Academy's report has identified, that the United States lacks an institutional capability for systematically evaluating the Nation's research enterprise, assessing its performance in developing some of these policy options for research. Isn't the

White House Office of Science and Technology Policy well positioned to perform that role?

Dr. FIENBERG. That office could be in a position to perform that role, but at the moment, at least, it really doesn't fit the formal mandate and it's overburdened with other activities. And so, there needs to be an organization not unlike that with the mandate to gather the data to integrate across agencies and to look independently at that. That's clearly one place to place such a capability.

Senator THUNE. Do you think that shortcoming in any way creates an impediment to growth, to economic growth?

Dr. FIENBERG. I think it has to.

If you want to know which of five programs or which of five different allocations across programs are going to yield the greatest benefit and you have no data and no insights, it's very hard to make policy choices on a rational, as opposed to a political, or other gut bases.

Senator THUNE. OK.

One final question, Mr. Chairman, I used twice my allotted time but I wanted to ask the question on the R&D tax credit.

Dr. Lane, you had mentioned, as I mentioned in my opening statement, you also highlighted, there are a lot of groups including the Business Roundtable that have suggested making that research credit permanent. How would that incentivize private businesses to unlock innovation and invest more in long-term R&D as well as promote jobs in manufacturing? Can you think of any specific examples of how our doing this in fits and starts and temporary extensions has inhibited companies long-term planning?

Dr. LANE. Well, thank you, Ranking Member Thune.

I think the purpose of that tax benefit was to encourage corporations to make some long-term investments in R&D because those really can constitute investments, and they're difficult to justify under certain circumstances. The idea of the R&E tax credit was to promote that because it was very important to the corporations to be able to look ahead further than they're currently able to do. The problem with making it temporary is that, or I hear from such corporations and Dr. Cerf can correct me if I'm wrong, is that when you don't know it's going to be their next year or the year after that, you're not going to make those kind of long-term commitments.

And so, one thing that does, I believe, is get in the way of a richer, stronger partnership between the private sector and the research universities of the country, and probably the national labs as well. So one thing that our committee is focused on is finding mechanisms to strengthen this partnership between the sectors. And there are a number of issues that we'll talk about, but one of them we think would definitely help is making this tax credit permanent.

Senator THUNE. Thank you.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you.

Would you forgive me if I asked one question?

Very smart man.

This is really to all of you. You've indicated about the importance of failure in broad Federal research. You say that "failure is the handmaiden of wisdom in the scientific world."

Now, that's a very hard concept for most people who are not scientists to understand in a political world much more difficult. Most people who work in government or private business want to be able to demonstrate that their investments have been successful. Now, what I would like you to do, each of you or any of you, is to give me an example, hopefully a real live example, of where you had to fail in order to succeed; number one.

Ms. DiChristina, I'd be interested in your thought on this, too.

Second, that it's sort of axiomatic, and Senator Thune has brought in another thing to this permanent tax credit, that you enable business to have more confidence into their future; therefore, they're more likely to invest. But underwriting I think your testimony is sort of an axiomatic matter that the private sector has to, at some point earlier than is convenient for the genius of failing in order to learn more, has to see results.

There are some huge companies; pharmaceuticals spent years working on things, though that's not the same. So if you could help me understand through precise examples of where the private sector just had to get out of your joint partnership because they could not justify to their board of directors or to their shareholders continued non-success. It's a very important principle because the people who do research at a lot of these private sector businesses are trained highly like you are. And they are genuine scientists. And they're driven by the same desire to get a result and have to at least in their own thinking realize that sometimes we have to fail in order to drive us to figure out why we failed, therefore come to a high level of understanding. So help me understand that in the real world.

Dr. CERF. OK. Thank you very much, Mr. Chairman.

Several examples. You will recall how many times Edison tried different ways at making a light bulb with different materials. And the point there is very clear that he had to fail a lot before he found something that worked. And what's important about this is failing fast as opposed to failing forever. And it's very important in the scientific enterprise and in business enterprise to learn quickly what works and what doesn't work. And so it's important to accept the idea that you want to learn from a failure. It's not that you want to fail but if you're going to fail you want to fail quickly and figure out why and try to be successful the next time.

I'll give you another scientific example. Newton's model of the universe was very successful except there were certain anomalies that it didn't explain. And it was the failure to explain that led Einstein to come up with a very alternative model. And, of course without repeating the rest of history, the quantum theory guys demonstrated that some of Einstein's theories didn't work under certain conditions. And again, the failure of the theory has led to and forced development of better theories.

And to give you another concrete, from my own personal experience, the first design of the Internet didn't work right. The second design didn't either. The third design didn't either. And the only way to find that out was to implement it and see what went wrong.

It's not that we thought that we were doing it wrong we thought we were——

The CHAIRMAN. It was as if it were the answer. You'd arrived at the answer.

Dr. CERF. I'm sorry?

The CHAIRMAN. To implement it because in order to have it a failure you had to assume that it was going to work so that it could fail.

Dr. CERF. Yes, but we didn't deliberately set about designing something that we knew wasn't going to work. Yes, we weren't that stupid. But we were stupid enough to try out something we thought would work and it didn't. And what was important is that we discovered very quickly that something didn't work, we discovered why it didn't work. We reiterated four times. The version of the Internet you're using today went through four cycles of that and I've been through exactly that same scenario with an interplanetary extension of the Internet. We went through multiple cycles of trying to design until we found something that worked right.

I think in the business world it's the same thing, except not all businesses either feel the freedom to allow people to try something ambitious that might not work. And at Google, I must tell you, the top of the company insists that we shoot for the moon, literally. We have an organization called Google X. It's the one that does the self-driving cars. It's the one that does Google Glass. It's the one that just invented a contact lens that measures the level of glucose in the tears of your eyes, calculates what the blood level of glucose would be and therefore would allow a diabetic—this is not operational yet—not to have to prick his fingers four or five times a day to figure out what kind of insulin should be taken.

These are moon shot things. And the company allows our engineers to try them out. Not every company, I think, feels the same level of willingness to do that. And so it's very possible that, for some other companies, this R&D credit that you were asking Dr. Lane about, might have an influence on their decisions. I'm lucky to work at a company that insists that we try things out even if we're not sure they're going to work.

Dr. LANE. Mr. Chairman, could I add a comment; just a brief comment?

The CHAIRMAN. Yes.

Dr. LANE. In a way, research is mainly about failure. I mean, the research projects I know about, either my own institution or the ones we funded, the researcher fails again and again. And you try this. It doesn't work. You try this. It doesn't work. You learn from it to try something else that doesn't work. You don't publish all the failures but that's what occurring day-by-day.

Dr. CERF. And maybe we should.

Dr. LANE. Maybe we should, but most of the time in the laboratory you're failing and learning and failing again and learning. That is the nature of research and that's a reason why whoever funds that research has got to have the patience to understand that process and be willing to live with it. Otherwise, we're not going to get it done.

The CHAIRMAN. And the continuity of funding.

Dr. LANE. Right.

Dr. FIENBERG. I——

The CHAIRMAN. Please.

Dr. FIENBERG. If I would be allowed, I could give a very different personal answer. When I was a graduate student, my advisor and a group of others at the National Academies were trying to answer a very vexing question about whether an anesthetic called halothane caused people to die when they had operations on their kidneys. And a number of deaths had occurred and nobody could understand whether or not this anesthetic was the cause.

We set about to develop new statistical models to address that problem. The data were manifold; people could not fit the data into the computers at the time. So everybody had to invent work-arounds and people proposed the theories, statistical theory for doing that that was now quite correct. After that report was published, I worked on that problem for 4 years and I published three papers and still didn't get the theory correct.

A decade later, with funding from ONR, from DOD, I worked on it again with the collaborators and we got really close. We had a manuscript of 200 pages, except there was a hole in the theorem and we never published it. And two decades went by again and, with NSF funding, one of my Ph.D. students took new mathematical tools, proved the theorem and those ideas turned out to be exactly what my friend and former colleague who was running Google Pittsburgh was using in his research on advertising for Google. And that was a 40-year legacy of efforts and, ultimately, we just published the results 3 years ago.

The CHAIRMAN. Thank you, sir.

Senator Markey.

STATEMENT OF HON. EDWARD MARKEY, U.S. SENATOR FROM MASSACHUSETTS

Senator MARKEY. Thank you, Mr. Chairman, very much and thank you for having this extremely important hearing.

Research and development science is critical to our economic growth, critical to keeping our lead in the world. We're looking over our shoulder at number two, three and four. We are winning Nobel Prizes this year because of an investment 30 or 40 years ago in young scientist, young technologists. Whether or not we are going to be successful 30 and 40 years from now and winning Nobel Prizes against China and India is going to be determined by the vision that this generation has. The last generation had one. Will this one? And will it ultimately be at the same level of results of fruit that the last generation is able to enjoy looking at the disproportionate number of Nobel Prizes in science that we win today?

So, Dr. Cerf, I just want to go back in time if I can. We've known each other for a long, long time. If you could take us back in time: It's 1966 and the Federal Government goes to AT&T and says "We'd like you to design a packet-switched network."

And AT&T says, "No, no, no. No, thank you. We already have a monopoly. We have the long lines going across America, we don't have time."

Then they went to IBM and said, "We'd like you to develop a packet-switched network."

And they say, "No, we don't want to do that."

And so, they go to a little company, Bolt, Beranek and Newman, up in Cambridge and they get the contract to design this packet-switched network. And then you and Bob Kahn and a whole bunch of other people, you know, playing off this Federal funding that's coming in. You kind of invent something here that's new and cool and it's not just applicable to defense but for the private sector as well.

Talk about a little bit of the role that the Federal Government played in having the vision not to invent it but to invest in the people and the science and the research that could invent it.

Dr. CERF. But, you know, in all fairness, the then Director of the Information Processing Techniques Office, Licklider, was in fact one of the creators of the concept. You will recall a very famous note that he sent around in 1965 to his colleagues to talk to them about his idea for an intergalactic network. And of course, he was just tongue and cheek, but he had the belief that computers could be used for more than just computation, that they could be used for dealing with non-numeric problems and could be used in command and control. And that was what drove the early ARPA initiative in the use of computing.

Second thing is that, in the run-up to the ARPANET, Larry Roberts was brought down from Lincoln Laboratory to ARPA. ARPA had been funding something like a dozen universities to do research in computer science and artificial intelligence. And every year each of those universities asked ARPA for the latest computing equipment because, after all, you can't do world-class computing without a world-class computer. And even ARPA couldn't afford every year to buy another world-class computer for every one of these research institutions. And so, Larry Roberts said, "We're going to build a network and you're going to share." Everybody hated the idea and he said "We're building the network anyway."

So that first network, the ARPANET, was a resource sharing network and it was driven by the government guys.

Senator MARKEY. Yes.

Dr. CERF. So the bottom-line on all this is that ARPA and the Department of Energy and NASA and the National Science Foundation, together, have funded network research for almost 40 years.

Senator MARKEY. So the bottom-line is no Federal Government, no funding——

Dr. CERF. None of this would have happened.

Senator MARKEY. No Bolt, Beranek and Newman. No invention of ARPANET. No Google. No Hulu. No YouTube.

Dr. CERF. No Yahoo!. No nothing.

Senator MARKEY. So just to say the words. I just want to say the words; okay?

And even today, what new things are coming to Google as possibilities because of that investment? Because of what is being done by the Federal Government?

Dr. CERF. So I think that the two most important things that I see at Google right now, apart from the really crazy stuff like the autonomous vehicles and the balloons that are floating at 60,000 feet delivering Wi-Fi services and the lens that I just mentioned earlier, those are our kind of moon-shot programs. But Google is all about organizing information. That's what our motto says: "Organize the world's information and make it accessible and useful." The idea that people want to share what they know with everyone else is the avalanche that happened when the World Wide Web struck in 1993. And Google is taking advantage of that ability to find and share information, help people discover information.

The second thing that's going on is the Internet of things is upon us, and Google just made an investment in a company called NEST; its early foray into that. The idea of having ordinary equipment being able to communicate with each other, with us and to aggregate that information to create Smart Homes and Smart Offices, Smart Cars and Smart Cities, and maybe someday Smart Continents. That's what I see the future is about because it's about getting the information and being able to do something useful with it.

Mr. Fienberg is going to be important to that, and his colleagues and his students, because analyzing this statistically will turn out to produce some very, very deep insights that you couldn't get if you couldn't manage all that information.

Senator MARKEY. I'm presiding over the Senate in 14 minutes so I have to run out, but I would just like to say that I said BBN, Bolt, Beranek and Newman, got the contract to do it and then everything flowed out of that but Leo Beranek, who is the owner, he eventually was the head of Channel 5, the ABC affiliate up in Boston. He was the Chairman of that Board.

So in the late 1970s he would sit there with me and he would just explain how these lines on a TV screen are just information and how eventually it was just going to be all digital and the screen would actually have data as well as a picture and a voice and how it was all going to evolve very rapidly, this guy who got the contract from ARPANET to build, you know. And so, he would explain it to me in the late 1970s, I would try to explain it to other people who, I was a Member of Congress, but the Committee up in the House wasn't yet ready for this level of, you know, it was still a far off event. But he always kept coming back to first you had to break up AT&T who didn't want the contract in 1965.

He would keep coming back to the central point that, unfortunately, there were many Nobel Prizes being won but it was off of basic research, none of it for applied; OK? If you got to get it out of the laboratories, get it out there and then the young people will take over.

And I will just say one final thing, because I do have to run. And that's to you, Dr. Lane. One of the most incredible moments that you have as a boy whose father is a milk man is you're a Cub Scout and Mrs. Carrie used to put the ten of us in a little van, you know, and take us around to see interesting things that we otherwise see from our neighborhood. And when we were ten, we went to the Museum of Science in Cambridge, you know? And the National Academy of Arts and Science is up there in Cambridge.

And thank you so much for all of your leadership, Dr. Lane. We really appreciate it.

But, as we were taken through that Museum of Science, it was eye-opening to us; huh? And we were the Catholic boys, you know, from Malden. It turns out is that it wasn't just the Catholic boys, but the Protestant, the Jewish, the Hindu, the Muslim, the Jain;

everyone was put on a bus and taken there when they were 10 years old, 11 years old because, regardless of the religion, science was in answer to our prayers. It could solve problems.

And so, scientific education is just so important and it's just something that we have to continue to invest in and revere. And I just want to thank you, Dr. Fienberg, Dr. Lane, Ms. DiChristina and you, Vint. Thank you all so much for all of your great work. Thanks.

The CHAIRMAN. Now you're not signing off are you?

Senator MARKEY. I'm presiding. I have to run.

The CHAIRMAN. Well just let the Senate idle.

[Laughter.]

The CHAIRMAN. You're more important here. You're just going to sit there presiding over people who aren't talking.

[Laughter.]

Senator MARKEY. Thank you.

The CHAIRMAN. OK. Thank you, Senator Markey.

We have the Commerce Committee and remember, again, going back to Chuck Vest. He would come down and there would be about four or five of us sitting around and he would just go into a hardcore get-with-it on science. I mean this; I'm talking 10, 12, 15 years ago, 20 years ago. And he'd just do it and he would do it because he was determined to try and make the Commerce Committee more receptive to the things that he knew were important. And what's happened now, interesting, is that we have like Ed Markey and Richard Blumenthal and others that are extraordinarily adept, good thinkers on the Commerce Committee. But we're caught in a time when the Congress doesn't want to do anything. So it makes it kind of difficult.

Now I want to ask a question to you, Dr. Cerf, and then I want ask a question to you, Ms. DiChristina.

Dr. Cerf, a few years ago you testified before this committee about the importance of the standards, TCP/IP, standards that you helped develop for the Internet. They're open. They're public standards that are available to anybody. Nobody has to ask permission to pay a royalty to use these standards. For example, Google didn't have to get permission for an Internet gatekeeper before it launched its search engine back in 1998 because it was all there. So these open standards have been one of the secrets to the success of the Internet; I would judge you agree. Isn't it true that because the United States led the effort to develop the Internet, we were able to prevail in the debate over open versus closed standards?

And second, I know you think a lot about this issue and I appreciate your roles in outside advisory to NIST. If the U.S. loses its role as a technology leader, won't we also lose our leadership role in developing standards that encourage openness and economic growth?

Dr. CERF. Thank you very much, Mr. Chairman. Those are both really important questions.

First observation I would make about standards is that they are a substitute for an endless amount of negotiation. When you agree on a standard, especially if it's a global and international one, and everyone chooses to adopt the standard, what it means, in my case and in the case of TCP/IP, is that two completely independent parties who never, ever met, never had a discussion or a debate, if they build their equipment to meet those standards, they will interoperate. That's why when you plug your computer into the Internet you can talk to 3 billion other devices anywhere on the Internet because they all observe, voluntarily, the same set of standards.

So it's a tremendous platform for innovation and creation and competition. Some people will tell you, "Oh, standards stifle innovation." Wrong. Standards create an environment in which lots of competition and lots of innovation are possible when you build on top of those standards. So that's the first point.

I'm sorry, but I forgot what the second question was. Help?

The CHAIRMAN. It has to do with your working with NIST.

Dr. CERF. Oh, with NIST. OK.

So the question there is what happens if we don't adopt and use these standards. NIST is one of the key players in standards-making for the Federal Government, and one thing that's very clear is that industry benefits enormously from having those standards around for exactly the same reason. And if we lose the leadership in the creation of those standards, then we will lose some of the momentum that the U.S. has been able to use to propel our industry. This doesn't mean, by the way, that we can't adopt and use other people's standards because we use international standards from other organizations like the International Standards Organization or the International Telecommunication Union. We participate in the creation of those standards but it's the ability to adopt and use them quickly and effectively that's the most important thing. NIST has helped with that and especially for the Government enterprise and for the private sector.

The CHAIRMAN. You know it's interesting because NIST has become, wrongly, very controversial in the whole question of trying to pass the cybersecurity bill. Olympia Snowe, since departed unfortunately, not from life but from this Senate, and I put out a cybersecurity bill 4 years ago, which seems like 30 years ago to me. And what was key to that was that NIST was deemed to be that organization which could bring private industry and the public sector together to figure out what were the basic standards that had to be met in order for somebody to, let's say, get liability protection as they try to protect themselves against hacking. And it became very controversial because part of the Senate said, "No, we don't want to have NIST making judgments. We can't have the government making judgment about what level of standards."

But on the other hand, if you don't have a level of standards in cybersecurity then, since it's all voluntary anyway, you end up with nothing.

Dr. CERF. Is there a question in there?

The CHAIRMAN. No.

[Laughter.]

Dr. CERF. First of all, NIST is one of the few bodies in the Government which regularly interacts with, has convening power for bringing the private sector and Government agencies together. And I think, as the former Chairman of the visiting committee on advanced technology, that NIST does this extremely well.

I think your point should be very well taken. That if we have no standards for security or safety, then how does anyone even judge how well these systems are protected. The problem is very hard. Protecting against attacks in the cyberspace is very difficult for the very simple reason that software has bugs. And I'm embarrassed to tell you that, as a former programmer and as a current user, we don't know how to write software that has no bugs. But we could certainly do better than we do now. And that's why we need at least standards that could be voluntarily adopted.

So I hope that you will continue in your effort.

The CHAIRMAN. Oh, I will.

I mean I just think, without sort of a common accepted standard that protecting yourself against cybersecurity doesn't have any meaning. And particularly in a body like the Congress where liability protection becomes such an enormous—we had to go through this on FISA. We had to give Verizon and AT&T protection on FISA because we were using their servers all over the world and they were getting massive, you know, claims made against them; suits brought in front of them because they were so doing. But they were so doing at our direction, the government's direction. So everything rolls around liability protection.

Dr. CERF. One of the biggest problems, I think, anyone would have including NIST is figuring out how to measure how secure or how well secured something is. And I think this is still the subject of considerable amount of research. And the reason for this, quite frankly, is it's made out of software, and software is really tricky complicated stuff. But that shouldn't stop us from at least trying hard to figure out ways to evaluate the security and safety of software.

And I think, Professor Fienberg, this might be yet another problem to land in the lap of the statisticians among others.

The CHAIRMAN. Thank you.

Now, Dr. DiChristina, I just came from what is almost my favorite meeting of the year, which is the National Youth Science Camp which is located actually in West Virginia, eight miles from my farm. And within the protection of the radio astronomy collection of operations out there which you can't even run a car through that eight mile radius; that 10 mile radius. I mean it's so protected.

So it's a wonderful experience for them. They come from all over the country and they spend 2 weeks there. And they get pounded on STEM. Now I just came from, you know, 100 of these folks, all young. Almost all of whom have decided what they were going to do in life. The two from West Virginia: one had decided they wanted to be a molecular biologist and announced that to me; and the other said that she was going to be a surgeon. Well, they're still in school; OK? And there's a lot that happens between what you want to do and then what you get to do.

So Dr. DiChristina, if we accept as a matter of public policy that STEM, which now, you know, has good bipartisan momentum and a lot of money, in the training of teachers, in the picking out of course, and in the influencing of students to stick to the training of STEM before they decide what they want to do—and I'm making the judgment, perhaps wrong, that when young people, somebody 17 years old, says "I want to be a molecular biologist."

I say, "You don't have any idea what you want to be yet. Get out in the world. Get outside of your comfort zone. Go join the Peace

Corps." You know? "Go to some other country. Join VISTA. Do something, anything, to take you out of your pattern of self-perceived progression in life."

You've got the magazine. How do we encourage young people to stay loyal to STEM, frankly, not just for their own purposes but, frankly, for us being able to develop and keep the funding that's necessary?

Ms. DiCHRISTINA. Thank you, Mr. Chairman.

The CHAIRMAN. I'm asking you to be A propagandist, which is not fair.

[Laughter.]

Ms. DiCHRISTINA. Fortunately for me, it turns out to be a suitable role, I think. You've asked me a lovely question. Thanks very much.

And one that has both a simple and complicated answer to it. It lets me to circle back a bit to the conversation we were having earlier too; about failure and getting through a failure and succeeding, which is part of it as well. In fact, one thing I sometimes—when I'm in a kidding mood and people ask me, you know, "How did you get to be what you're doing?"

I tell them that I am, in many ways, a failed scientist. So when you think about, you know, if you'd asked me when I was younger, I was definitely going to be a scientist. I took all the classes in eighth grade. I was an "Alchemist," which was an after-school club, just so I could hang around and clean the test tubes and be longer around science.

And, I think, for many people and many young people especially, as Vint mentioned just a little while ago, you know, we've been called "born scientists." In fact, there's quite a body of research around that. Alison Gopnik and others have written about how it's innate to humanity to be curious, to ask questions, and you don't have to believe me. You can look at any young child in a highchair, dropping things off the side that weigh different amounts to see how they'll fall. That is a baby scientist.

But the problem for many of us is that, as we get older, we're not able to keep touch. And you already, Mr. Chairman, pointed that out. How can we keep them down the track so their minds are open and they're looking at things? And we thought a lot about that at *Scientific American,* of course, which is why we try to keep the doors open to inviting them in. And it's something that I recommend, indeed, to anybody who is trying to engage children. It's not just when they are very young, which is, in some cases, we do a pretty good job at. And *Scientific American* has a series of activities called "Bring Science Home," just to let parents and kids play with science.

But for many of us, as we get older, science becomes a place we haven't been. Maybe fewer than 20 percent of the American public has even ever met a scientist. In this I feel very wealthy because I've met many. But for many people, science is—well, let me put it this way. If you go to a new country, aren't you always more interested in that country after you've been there?

And science is a new country for many people. So the way to keep them engaged is to give them contact points. We've talked about a few of them. We talked about the Maker Movement. We've talked about citizen science and creating those open doors. These work all the way through the chain from when we're very young to when we're in middle school which, frankly, we lose a lot of people; in middle school which is why *Scientific American* has a matching service that gets scientists from every state in the union as volunteers into classrooms. It's on our website and it's for free. And then right up on through to when they're members of the American public and they can appreciate, by contacting science directly themselves, how it can help both inspire them and move the economy and our well-being through the future.

So how we do that? We keep the doors open. We keep them open in all the ways we can and it's, as usual, a wide set of arrays which gives us a lot of options because that gives us choices. You might like to do it online; I might like to go to a dig.

At the U.S.A. Science and Engineering Festival held here, in Washington, D.C. in April, 200,000 young people and families came through just to be close to science. At our booth, we let them actually handle media from fossil eras from 5 million years old. And we had discoveries that will be published right out of that booth made by children. That's the way to keep in contact with science; is do it directly.

Thanks very much.

The CHAIRMAN. No, thank you.

Let me just close with, you know, America is in some distress just now and we're going through problems of immigration and can we govern ourselves and why is it that we're sort of setting about to destroy the instruments of government, such as NIST and other things, through non-funding. It's interesting. Sometimes you have discussions now, and we do aviation on this committee. And the FAA really hasn't had any boost in funding for years, but they don't complain because they're not getting cut as much. But, if they have the same as they had the previous year, they've been cut. People just come to sort of accept that and that's a very bad point-of-view.

So let me ask you about the younger generation. I just did, intuitively—I mean, I was on cloud nine talking to that group. They were so bright. They were so good. They are from all over the world, but they represented, you know, two from each state. Then every time I've been there, which has been 8 or 9 years because West Virginia kind of does that, they're always the same.

So my question to you is: has there been, in this buffeting of the economics of progressing in life and surviving in life and paying off college this and graduate school that, has there been in your judgment a diminution in the number of young people and their interest in science and, more importantly, their commitment to actually do something about that interest?

Ms. DICHRISTINA. Thank you, again, for another lovely question.

So here I think this is a very important one, and I think that we are, of course, at risk if we don't choose the right policies to enable the students to keep that exploration that we were just talking about. But they do come in with that enthusiasm. They do start with it. At least some data evidence is helpful in this instance. We can see how they're reacting thanks to digital platforms, such as the ones that Vint, here, and others have been speaking about.

Google has something called a "Google Science Fair," which is a global competition. And every year it's got thousands and thousands of more students applying for it. What's different from that competition compared with the activity that you talked about which is one in person, which is wonderful and there should never be a substitute for being in-person with people. But thanks to the digital platforms that have been developed, thanks to Federal research over time, and vast collaborative networks, we can now enable students to participate in science and research at a greater level through those networks as well. It's another way for us to invite them in.

And through the Google Science Fair, these students can be anywhere around the world participating. In fact, *Scientific American* gives a special award called "Science and Action" which was first won by a pair of students in Swaziland who came up with a better way to feed their community.

So the digital platforms give us yet another way. There are lots of other ways we could talk about, but I think that we have to keep an eye on those filters; we have to keep them open so that we're not discouraging the students from continuing on.

Thank you.

The CHAIRMAN. I was really disheartened yesterday to read in *The Washington Post,* and that doesn't make it correct, that applications for the Peace Corps are down for the first time. And I'm trying my best not to make that into some kind of a broader pattern but just a temporary something or other.

Yes, sir.

Dr. CERF. May I?

One thing that occurs to me, Senator Rockefeller, is that I wonder whether the drumbeat of reports of turmoil around the world——

The CHAIRMAN. Would have——

Dr. CERF.—are causing some students to decide maybe it isn't safe to go and serve in that way.

But if I could pick up something that Ms. DiChristina mentioned, there has been something that's happened in the last four or 5 years that I believe is really going to be transformational for young people's interest in science and engineering. And the answer is these 3D printers, and it sounds like a trivial statement but let me tell you that when you can end up with a concrete thing that you did as opposed to a kind of ephemeral piece of software that got written in a program that ran, the concreteness of what comes out of the 3D printing program is something that solidifies people's interest in science and engineering. I made this, and I think that we are going to see a renaissance of excitement in science and technology as a result of that invention.

The CHAIRMAN. Yes, sir.

Dr. LANE. Senator, may I add a comment? This is another area where immigration is so important——

The CHAIRMAN. Yes.

Dr. LANE.—to our country.

In addition to the point you made about the contribution that had been made by generations of people coming here from all over the world for their education and starting companies and becoming a part of our society; their children go to our schools; they bring values from countries that, for whatever reasons, tend to consider science, engineering, and technology a higher priority somehow than America has been doing in recent decades.

Peer example is very important to young people and I think—I have grandchildren in schools with second-generation kids from all over the world. Kids who assume that it's very important for them to understand STEM subjects and the careers in STEM really are exciting careers to think about. This rubs off. I think it influences other young people and reinforces those who are already interested in science. But also, I think, it shows to a larger number of young people how important science, engineering, technology and mathematics really is.

So I think it's another side of immigration that this country has profited from over the years.

The CHAIRMAN. And also, maybe, just a touch of disgust on the part of younger people; of how my generation and younger-than-me generations have not done things adequately for their futures and, hence, the move toward more people becoming independents as opposed to Republicans or Democrats. In other words, that could be the surging of young people who, by definition, I think are always sort of created to be energetic and idealistic unless they're suppressed somehow. That may be what you're saying is absolutely right. And let's just assume that it is and we'll use that high note to end what has been an excellent hearing.

I apologize for being greedy and keeping you here but I've been looking forward to this for a long time to get such top people, virtually, alone and——

[Laughter.]

The CHAIRMAN.—be able to get answers. And there's a young woman named Ann Zulkolsky behind me who is even happier than I am about all of this.

So thank you for your time. I have absolutely no idea what time it is.

[Laughter.]

The CHAIRMAN. Or planes that you have to catch, but I don't care. You were here.

Hearing is adjourned.

[Whereupon, at 5:20 p.m., the hearing was adjourned.]

A P P E N D I X

EMERGING TECHNOLOGY CONSORTIUM
Washington, DC

Hon. JAY ROCKEFELLER,
Chairman,
U.S. Senate Committee on Commerce, Science, and Transportation,
Washington, DC.

Hon. JOHN THUNE,
Ranking Member,
U.S. Senate Committee on Commerce, Science, and Transportation,
Washington, DC.

Dear Chairman Rockefeller and Ranking Member Thune:

The Emerging Technology Consortium—a Non-Profit Economic Development Corporation—submits the attached article from *The Wall Street Journal* for inclusion in the record for the Commerce Committee's hearing on The Federal Research Portfolio: Capitalizing on the Investments in R&D held on July 17, 2014.

The Emerging Technology Consortium (ETC) is a non-profit organization dedicated to using technology and innovation to create opportunities in all communities—businesses with good paying jobs. The 21st Century global economy is open to companies that produce the right product and/or service. In America today, this can happen if Government, at all levels, leads public private partnerships that create globally competitive businesses. America competes globally when next generation industries are located in all communities. Leadership must understand that there is no short cut to creating good paying jobs; it starts with diversifying and the commercialization of research that creates next generation industries. Those new companies will be the educational catalyst because people can see good paying jobs in their communities. Diversifying participating in innovation ensures America's competitiveness in the 21st Century global economy.

America's competitiveness is predicated on all American's regardless of age, gender, race, national origin or religion, participating in research and commercialization activities. Noted scholars and university administrator are calling for a re-examine the grant review process as part of recalibrating our research policies.

Thank you for your consideration of this request.

DAROLD HAMLIN,
President and Executive Director,
Emerging Technology Consortium.

Attachment: Article Wall Street Journal, March 4, 2014 OPINION, "How to Reverse the Graying of Scientific Research" by Ronald J. Daniels and Paul Rothman

ATTACHMENT

Source:
http://www.wsj.com/news/articles/SB10001424052702304026804579411293375850348

OPINION

HOW TO REVERSE THE GRAYING OF SCIENTIFIC RESEARCH

Dramatically fewer grants are going to young scientists. That's a cause for alarm.

By Ronald J. Daniels and Paul Rothman—March 4, 2014 7:08 p.m. ET

Youth will be served, as the saying goes, but increasingly that's not the case in scientific research. The National Institutes of Health reports that between 1980 and 2012, the share of all research funding going to scientists under age 35 declined to 1.3 percent, from 5.6 percent. During the same period, the number of NIH awards going to scientists age 35 and under declined more than 40 percent, even as the total number of awards more than doubled.

The numbers are similarly unsettling for the NIH's premier research grant, called the R01, a highly competitive, peer-reviewed grant that supports independent, investigator-driven science. From 1983 to 2010, the percentage of R01 investigators under age 36 declined to 3 percent from 18 percent. Principal investigators who were age 65 or older received more than twice as many R01 grants in 2010 as those 36 and under—a reversal from 15 years earlier. The average age at which investigators with a medical degree received their first R01 grant rose to 45 in 2011, from 38 in 1980.

Considering that many of the most significant scientific breakthroughs were made by the 36-and-younger set—from Albert Einstein developing his special theory of relativity at 26 to James Watson at 25 and Francis Crick at 36 discovering the DNA double helix—we deprive young scientists of funding at our peril.

The reason fewer young scientists are receiving R01 grants from the NIH is not, as some observers surmise, because the researchers are securing alternative grants tailored to young investigators.

Getty Images/Fotosearch RF

So what explains the tilt away from them? There are the long years spent in doctoral and postdoctoral programs or the technical requirements of the grant application. Or there is the length of the review process itself, as a closed system that disfavors the daring idea or the lesser-known applicant. This tendency is only more pronounced in an age of strained Federal research funding: With a smaller pot of money to dispense, there is even less incentive to support the risky proposal or the new scientist.

Our most promising young minds find it more difficult than ever to ignite their own research. More young scientists are leaving laboratories for careers in industry. Some 18 percent of young scientists are considering leaving the country for positions abroad, where research funding is on the rise, according to a 2013 study by the American Society for Biochemistry and Molecular Biology.

The NIH has not sat idly by. The agency has launched special award programs for investigators within several years of earning an M.D. or Ph.D. It also has created a "new innovator award" for investigators with unusually creative research ideas, and designed special rules to direct more R01 funding to early career investigators. But none of the initiatives in place has succeeded in reversing the trend toward reduced funding for young scientists.

Many young scientists are not ready to lead a lab, and experienced investigators advance innovative research on a daily basis. And at least one recent study suggests that as the realm of knowledge has expanded, the age at which researchers can produce innovative science is inching ever upward.

Nevertheless, history has shown that it is often the youngest scientists who defy orthodoxy and shatter paradigms. We must recalibrate our research policies to fuel the promise of the most talented individuals of all ages, with solutions on three fronts: re-investment, re-examination and re-imagination.

First, we must restore the national commitment to funding scientific research. Over the past 10 years, the NIH has absorbed cuts in purchasing power in excess of 20 percent, and this overriding trend is the greatest threat to nascent scientists. As these funds are restored to the agency, a substantial portion should be invested in awards tailored to young scientists.

Second, we must re-examine the grant review process. The U.S. was the birthplace of peer review for research grants, and others adopted it to remarkable effect globally. This country should now lead in diversifying the pool of reviewers and, by this and other mechanisms, reduce the advantage of experience.

Third, and more ambitiously, we should re-imagine the NIH grant to alleviate the pressures that currently steer R01 funding away from young scientists. We could increase the availability of grants designated for young investigators, create a funding stream for smaller demonstration projects that allow new scientists to obtain preliminary data for an ensuing application, or fund a capstone award for experienced scientists to complete their lines of study and preserve the legacy of their work.

Other countries, including South Korea, Sweden and Israel, are pulling ahead of the U.S. in research and development investment as a percentage of GDP. These same countries are surpassing us in particular in their commitment to the next generation of scientists. China recently issued a strategic plan to build its science and technology workforce by cultivating 3,000 of the most talented young scientists over the next 10 years.

We will put our Nation at risk if we fail to make a comparable commitment. If we miss out on investing in the next generation of scientists, we will miss out on their discoveries as well—and the benefits we all reap in improved drugs, technologies and jobs.

Mr. Daniels is President of Johns Hopkins University. Mr. Rothman is CEO of Johns Hopkins Medicine and dean of Johns Hopkins School of Medicine.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. AMY KLOBUCHAR TO DR. VINTON G. CERF

Question 1. Investment in computer science education is essential if we want to maintain and grow the STEM workforce in the United States. That's why I introduced the Innovate America Act with Senator Hoeven, which would expand STEM education opportunities to kids across the country by increasing the number of STEM secondary schools in the United States and boosting computer science investments. Do you believe that increasing the number of STEM schools would increase the retention of students pursuing a college degree in the STEM fields?

Answer. It is not clear to me that increasing the number of STEM schools would be as effective as ensuring STEM teachers at existing schools have the qualifications and resources they need. The most effective path forward is to ensure we have teachers with serious college credentials in the sciences and other STEM disciplines who can convey the excitement and substance of science and technology. That means increasing incentives for teachers, providing for suitable facilities for teaching—including laboratory equipment—and investing in Internet-based resources—such as Massive, Online, Open Courses (MOOCs)—that could be integrated into the school curriculum. MOOCs have the potential to allow students to learn at their own pace, reviewing lecture material as needed. They enable classrooms to become places where problems are solved, techniques are discovered, and collaborative science is conducted.

Question 2. Do you believe we have a sufficient amount of computer science education in our elementary and high schools? What can be done to improve computer science education?

Answer. No, I do not. I think we should make exposure to programming a required course, or at least a course that can satisfy science curriculum requirements. There are two reasons for this view:

(1) Learning to program teaches a certain kind of analytical discipline, by building valuable skills such as dividing problems up into solvable components, understanding how to integrate the ensemble of software into a solution, and finding and fixing errors (bugs), among others.

(2) We are currently surrounded by software, and it will only be more so as the "Internet of Things" continues to expand. Smart cars, homes, cities, and nations will become a common part of our socio-economic landscape. It is important to prepare students to understand the power and the potential of computer-based systems while also providing them with a clear appreciation for the hazards they may pose. That includes understanding the opportunities and risks of online environments.

The Association for Computing Machinery (*www.acm.org/education*) and the Computer Science Teachers of America (*http://blog.acm.org/archives/csta/2014/08/*) are strong advocates of increasing the visibility and validity of computer science as a standard part of the STEM curriculum, not just an optional elective.

Regarding improvement of computer science education, I refer to the first question and my response. The key is to form teachers with much better preparation to help students learn about computing and to encourage participation in extra-curricular activities, such as the Maker Movement and robotics contests. (A good example is FIRST, For Inspiration and Recognition of Science and Technology, founded by inventor Dean Kamen and accessible at www.usfirst.org,). Bringing working scientists into the classroom or making them available online can also help. I find TED talks enormously stimulating—some of them make me want to go back to school!

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO DR. NEAL LANE

Question. Peer review directs our research dollars to the projects that experts in the field think have the most potential. It promotes competition and protects the scientific process from political pressures. Can you explain why it is so important to give our expert science agencies like DARPA, NSF, and NIST the ability to fund research based on the merits of the research, and not on a political agenda?

Answer. Peer review, as it is used here, refers to the process whereby the scientific and technical merit of a grant application is evaluated. This task is carried out by scientific "peers"–scientists who have expertise in a relevant discipline and specific area of research. Scientific expertise is crucial for understanding both the principals of the research proposal and its potential to advance a scientific field, wherein lies the true value of basic research. Breakthrough achievements in basic research have led to some of the greatest technological advancements, and were often pursued with no clear application in mind.

For example, the genomics revolution and the Human Genome Project were unleashed by the study of a thermophilic (heat tolerant) bacterium from Yellowstone national park. An important treatment for diabetes, the drug exenatide, grew out of early investigations into Gila Monster venom. Neither of these important applications could have been predicted. To address the high demand for kidneys and the challenge of finding a donor, economists developed algorithms to match biologically compatible donors to patients. And let us not forget the laser, which would not exist today without fundamental experiments aimed at generating a controlled, extended stream of microwaves through contact with a molecule in an excited state, a project that might have been considered frivolous at the time.

Each of these projects in basic research was funded by the Federal Government through the process of expert peer review. Were basic research proposals to be judged based on a political agenda, or even the expectation that an application would result, the American system that fuels the best research in the world would be put at risk.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. AMY KLOBUCHAR TO DR. NEAL LANE

Question 1. Investment in computer science education is essential if we want to maintain and grow the STEM workforce in the United States. That's why I introduced the Innovate America Act with Senator Hoeven, which would expand STEM education opportunities to kids across the country by increasing the number of STEM secondary schools in the United States and boosting computer science investments. Do you believe that increasing the number of STEM schools would increase the retention of students pursuing a college degree in the STEM fields?

Answer. While this question falls outside of my area of expertise, it would seem reasonable to expect the number of students pursuing a postsecondary degree in a STEM field to increase with the number of STEM schools, assuming that these schools are accessible, have effective teachers and up-to-date curricula, and are able to retain a high percentage of students from enrollment through degree attainment. STEM education, including computer skills, is critically important for developing the competitive workforce that this Nation needs—not only careers in science and engineering but many other occupations as well, including medicine, law, and business.

Question 2. Do you believe we have a sufficient amount of computer science education in our elementary and high schools? What can be done to improve computer science education?

Answer. This, too, falls outside of my area of expertise. But computer science is clearly an important part of primary and secondary education, and a valuable skill in today's job market. Employment in the computer sciences and math is expected to grow by 18 percent by 2022, and average annual wages (currently at $76,270) are expected to exceed $100,000.[1] However, according to a study by the National Center for Education Statistics, computer science is the only STEM field that has seen a *decrease* in student participation over the last 20 years, from 25 percent of high school students to only 19 percent in 2009.[2] The source of the problem may range from outdated and unexciting course curricula to limited availability of advanced classes.[3] Only 9 percent of schools offered AP computer science last year, and only 31,117 students took the AP computer science exam, compared with 282,814 students who took the AP calculus exam and 169,508 students who took the AP statistics exam.[4] The path to improving computer science education may begin with addressing these two shortcomings.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. EDWARD MARKEY TO DR. NEAL LANE

Question 1. Dr. Lane, in your testimony you emphasize the need for proactive polices that will maximize the benefit of the Federal R&D investment to the American people. One area you highlight is the need for a greater government-university-industry partnership. Your testimony alludes to the U.S. falling behind in this area. Can you expand on that and give us examples of what other countries are doing that we could learn from?

Answer. Today, most innovative and successful companies do not think of innovation as a linear, step-by-step process, moving from research to invention, then prototype, then product design, then marketing. Rather, ideas and data flow back and forth between the different groups involved in turning research into products and services—industry, universities, and government. In such an innovation ecosystem, there is an ongoing iterative dialogue between researchers, developers, and marketing teams. Innovation occurs in a web in which ideas, data, and people move freely, improving both the quality and speed of work.

Other nations have launched initiatives that encourage the transfer of people and ideas across sectors, including Germany (Fraunhofer Institutes), Taiwan (ITRI; Industrial Technology Research Institute) and Singapore (A*STAR; Agency for Science, Technology and Research). The nation that fosters partnerships and cooperation across government, industry and academia, as well as a balanced portfolio

[1] Emily Richards and David Terkanian, "Occupational employment projections to 2022," Monthly Labor Review, December 2013.
[2] National Center for Education Statistics, *America's High School Graduates: Results from the 2009 NAEP High School Transcript Study,* 2011.
[3] Keith Wagstaff, "Can we Fix Computer Science Education in America?", TIME, July 16, 2012, available at *http://techland.time.com/2012/07/16/can-we-fix-computer-science-education-in-america/*.
[4] College Board, "AP Program Participation and Performance Data 2013," 2014, available at *http://research.collegeboard.org/programs/ap/data/participation/2013.*

of basic and applied research will lead the globe in scientific and technological progress.

Question 2. Dr. Lane, why is it important for NSF and other agencies to support informal science education (ISE) programs? Can you provide us with examples of successful ISE programs and recommend ways Congress can strengthen these efforts supported by government science agencies?

Answer. Several Federal agencies invest in support of informal science, technology, engineering and mathematics education (ISE), including the Smithsonian Institution and NASA. The National Science Foundation (NSF) invests in a number of informal science education (ISE) or out-of-the-classroom activities. The primary NSF ISE program, Advancing Informal STEM Learning (AISL), seeks to advance new approaches to and evidence-based understanding of the design and development of STEM learning in informal environments. This program supports work in a variety of informal settings and resources such as broadcast media and film; science centers and museums; zoos and aquaria; botanical gardens and nature centers; libraries; digital media and gaming; youth, community, maker, and after-school programs; science communications; citizen science; and education research and evaluation. The AISL projects help broaden access to STEM learning experiences and give participants new opportunities to understand the world around them. In addition to AISL, NSF funding supports a number of other programs with ISE components such as Cyberlearning and Future Learning Technologies; Discovery Research K–12 (DRK–12); and Innovative Technology Experiences for Students and Teachers (I–TEST).

NSF is committed to supporting the research and development of ISE programs in order to identify and understand the mechanisms that drive effective outcomes. ISE has the potential to kindle an interest in STEM and to spark the creativity that leads to both discovery and innovation. These activities also contribute to a science-literate citizenry that fosters the basic research critical to building a STEM-driven economy.

Congress can strengthen ISE by continuing to encourage efforts to build the body of knowledge around what works, for whom, and under what conditions for learning in informal settings, and in how such experiences motivate and engage youth and the public. Increased support would allow more research and evaluation in order to identify innovative practices and learning experiences that advance engagement with and understanding of STEM subjects. Collaborations across agencies that enable the assets of the science mission agencies, through partnership with NSF, the Smithsonian, and the U.S. Department of Education, to be deployed at large scale to reach and inspire many youth across the Nation should be encouraged. Harnessing the lessons learned from leading practices creates the potential to expand the impact of successful programs through the dissemination of key findings and the scaling of evidence-based models.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO DR. STEPHEN FIENBERG

Question. Peer review directs our research dollars to the projects that experts in the field think have the most potential. It promotes competition and protects the scientific process from political pressures. Can you explain why it is so important to give our expert science agencies like DARPA, NSF, and NIST the ability to fund research based on the merits of the research, and not on a political agenda?

Answer. Policies established through our political process are important to decide how much Federal funds will be invested in research and the relative importance of national goals for research investments, such as health, the economy, the environment, and energy. But those decisions are very different from identifying quality science and the scientists where we are most likely to achieve transformative results. Only peer review by scientists can assess the latter.

Picking specific research projects or even scientific disciplines to be funded through a political process and favoring them at the expense of others is a mistake: it could lead to unintended consequences that actually impede research and stunt innovation. Scientific discoveries that eventually lead to truly transformative innovations often depend on high quality research in variety of fields that could not be predicted in advance.

As we noted in our report, Furthering America's Research Enterprise, increased benefits of the Federal investment in research are far more likely to flow by promoting the conditions for the research enterprise to thrive. The three most important conditions are what we call the crucial pillars of the research enterprise. These are:

(1) a talented and interconnected workforce,

(2) adequate and dependable resources, and

(3) world-class basic research in all major areas of science.

We cannot assure the stock of knowledge from research of world-class quality through a political process. The best way we have is through the quality control system of peer-review.

So, for example, the political process may determine the relative importance of research on developing better batteries. But the real breakthroughs may come from basic research in chemistry and materials science, and the statistical design of new experiments for testing, as well as social science research on the adaptation of new technologies.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. AMY KLOBUCHAR TO DR. STEPHEN FIENBERG

Question. Investment in computer science education is essential if we want to maintain and grow the STEM workforce in the United States. That's why I introduced the Innovate America Act with Senator Hoeven, which would expand STEM education opportunities to kids across the country by increasing the number of STEM secondary schools in the United States and boosting computer science investments. Do you believe that increasing the number of STEM schools would increase the retention of students pursuing a college degree in the STEM fields? Do you believe we have a sufficient amount of computer science education in our elementary and high schools? What can be done to improve computer science education?

Answer. As important as these questions are, we lack data and research to provide clear answers. One issue, for example, is how to disentangle the effects of STEM schools from the students who attend these schools. Nevertheless, many observers view STEM schools as the best route to achieve desired STEM outcomes. And we do have knowledge from research that speaks, albeit indirectly, to the question you raise about increasing the number of STEM schools. This research is described in another National Research Council report, *Successful K–12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics.* Thus to address aspects of your question I have relied on input from colleagues at the National Research Council.

Preliminary research results indicate that the experiences of students who graduate from selective schools appear to be associated with their choice to pursue and complete a STEM major. "Yet," as the report notes, "there are no systematic data that show whether the highly capable students who attend those schools would have been just as likely to pursue a STEM major or related career or make significant contributions to technology or science if they had attended another type of school. Furthermore, specialized models of STEM schooling are difficult to replicate on a larger scale because the context in which a school is located may facilitate or constrain its success. Specialized STEM schools often benefit from a high level of resources, a highly motivated student body, and freedom from state testing requirements. These conditions would be difficult, if not impossible, to implement more widely." (NRC, 2011, p. 8)

Nevertheless, the report notes from preliminary research that "students who had research experiences in high school, who undertook an apprenticed mentorship or internship, and whose teachers connected the content across different STEM courses were more likely to complete a STEM major than their peers who did not report these experiences." (NRC, 2011, p. 9)

Whether the amount of computer science education in our elementary and high schools is sufficient is another question for which we need research. A critical element of such research is the clear definition of outcomes.

Thus, to truly answer both questions, what we need are data that track the educational choices and progress of students over time, including post-secondary outcomes.

Reference

National Research Council (2011). *Successful K–12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics.* Committee on Highly Successful Science Programs for K–12 Science Education. Board on Science Education and Board on Testing and Assessment, Division of Behavioral and Social Sciences and Education. Washington, D.C.: The National Academies Press.

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