Challenges in the Sciences:
Educational Policy, the Academy, and Funding for Research

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Introduction

> "New frontiers of the mind are before us, and if they are pioneered with the same vision, boldness, and drive with which we have waged this war we can create a fuller and more fruitful employment and a fuller and more fruitful life." [1]

This quote, from a letter written on November 17, 1944, by President Franklin D. Roosevelt to Dr. Vannevar Bush, then the Director of the Office of Scientific Research and Development, provided the vision for what was to become the National Science Foundation, and more generally, a tradition of sustained government funding for science and engineering research. At that time, significant resources were being contributed to wartime efforts, including basic and applied science research directed toward national welfare. President Roosevelt had the foresight to advocate continued support for science research following the conclusion of the World War II to ensure the creation of new jobs, an improvement in the standard of living, and increased national security. Vannevar Bush's response to President Roosevelt was framed in the document *Science—The Endless Frontier* [1], which ultimately led to the creation of the National Science Foundation.

Now, more than 65 years and roughly three generations of scientists later, it's worthwhile to evaluate how President Roosevelt's vision has fared. Today, science research—or more broadly science, technology, engineering, and mathematics (STEM) research—continues to be seen as vital to the economy and national security of the United States. The problem of renewing scientific talent, identified by President Roosevelt as one of the four critical areas of national concern, continues to be a problem today, although for a different reason. During World War II there was a deficit in science and technology students because large numbers of able-bodied men were serving in the armed forces. The deficit in trained STEM personnel exists today not because of wartime service, but because of declining interest in pursuing STEM careers.

In this paper, we will follow the beginnings of a national, intentional effort to position the United States as a leader in science research. The early struggles in establishing a central agency to define science policy and fund research provide an interesting backdrop to the current state of science research. The areas identified by President Roosevelt as critical to maintaining the United States' pre-eminence as a global leader have not changed; instead, the nature of the threats to those areas has changed. Globalization, in particular, has critically altered the standing of the U.S. in STEM research and education. The recent National Academies reports, *Rising Above the Gathering Storm* [2] and *Rising Above the Gathering Storm, Revisited* [3], formulate an action plan "to enhance the science and technology enterprise so that the United States can successfully compete, prosper, and be secure in the global community of the 21st century." We will also discuss the recommendations of these reports with regard to formulating education policy and developing research funding.

The Efforts to Establish Government Support of Science Research

Prior to World War II, federal support of science research was primarily limited to activities in government labs, focused on projects deemed important to national interests. [4] In 1944, President Franklin Roosevelt wrote a letter to Dr. Vannevar Bush asking for his recommendations for a government post-war research policy focused on four points: [1]

- How to document to the scientific community the research conducted during the war;
- How to promote scientific research that will aid in fighting diseases;

- How to aid science research conducted by public and private institutions;
- How to at least maintain the wartime efforts in science research by ensuring an adequate supply of trained scientists.

At that time, Bush was the director of the Office of Scientific Research and Development. In this role, Bush oversaw scientific research efforts directed at wartime applications, and much of this work was classified. President Roosevelt's intent was for Bush to transfer the knowledge gained through these efforts to ensure the creation of new jobs, an improvement in the standard of living, and increased national security in peacetime.

It is interesting to note that Bush, as the president's informal science advisor, persuaded President Roosevelt to request these recommendations on a post-war research policy. [4] This action was motivated by Bush's desire to control the direction of this policy. It is important to understand the political climate that existed when Bush drafted this letter for the president. While Bush was advocating for a policy that emphasized basic research funded by the government and ownership of the research by the investigators, Senator Harvey Kilgore was instead advocating for a policy that ceded all control of the research to the government. [4] Kilgore, a New Deal Democratic senator from West Virginia, wanted one agency that would coordinate all public and private research activities, set the priorities for science research, ensure the application of the research results for the public good, and distribute the research monies so as to support a broad array of research projects. Kilgore's plan would also make use of a board, with its members selected by the president, to distribute the monies and disseminate the research results. This difference between the two positions is often framed as that of a liberal politician versus a conservative scientist (see, for example, Wang [5]), but we would instead identify as more important the issue of autonomy of the investigator in science research. As Bush stated,

"…Science flourishes to the greatest degree when it is most free….We should bend our efforts, not to perpetuate any of the necessary wartime controls which we have created for our defense, but rather to return the maximum of independence to our scientific institutions and our scientific men.…" [6]

Kilgore was most interested in making sure that research funded by the government was directed toward specific solving of problems in society. [4,7] He was motivated in this regard by his belief that the government and industries had failed to prepare adequately for World War II. Kilgore's reasoning for a central agency stemmed from his perception of a lack of coordination among government agencies, academic institutions, and private industries in science research, of the "monopoly" a few institutions had on research activities, and of patent rights preventing research results from public dissemination. Kilgore's first bill, the Technology Mobilization Act (S. 2721), was widely debated but was never put up for a vote; scientists were opposed to relinquishing decision-making to the government on matters concerning science research. Kilgore's second bill, the Science Mobilization Bill (S. 702), was directed at creating a central agency to establish policies and priorities for science research and subsequent technology development. This bill, too, faced significant opposition, especially from organizations representing scientists including the American Association for the Advancement of Science (AAAS), the American Chemical Society (ACS), and the American Institute of Physics (AIP) (see, for example, the response from the ACS [8]).

Perhaps more importantly, this second bill was opposed by Bush. Bush, writing in the journal *Science* (which is published by AAAS), discussed the effects of Kilgore's bill on both wartime and peacetime science research policy and funding. [6] While Bush agreed that centralized control of research was best in times of war, he argued that freedom in research was essential during times of peace. His position was one of science research funded by the government but yet free from control of the government; that is, Bush's vision was that of scientists receiving federal funding to perform basic science research without the government dictating the topics or direction of the research. Bush clearly did not advocate the involvement of non-scientists in the funding of science research.

Once again, Kilgore did not put this second bill up for a vote. Two years later, the Senate subcommittee that he chaired released a report affirming his position. [8] The report called for a central scientific agency to define which projects were in most need of receiving funding, with emphasis on both basic and applied research. The report also called for increased public input on decision-making regarding science policy.

It was in this context that Bush persuaded President Roosevelt to write him the letter dated November 17, 1944, asking for Bush's recommendations for a government post-war research policy. To respond to President Roosevelt's request, Bush organized four committees, one to address each of the points in the president's letter, and less than ten months later, in July 1945, Bush and his committees issued the report *Science—The Endless Frontier*. The position expressed in this report differed from that of Kilgore in the following ways. Bush's report advocated for a central science agency—a referred to as the National Research Foundation—overseen by scientists (not the public) that would provide funding for *basic* science research without dictating research policy.

While the Bush report was issued in July 1945, the National *Science* Foundation (NSF, a name first suggested by Kilgore) was not established until 1950. Following President Roosevelt's death in April 1945, President Truman asked Congress to further study the recommendations from Bush's report. This lead to a period of five years during which the merits of both positions—Bush's and Kilgore's—were debated in the legislature. The 1950 National Science Foundation Act created an agency and a structure for science research that mirrored Bush's proposal. The president had the ability to select the director and board of the Foundation, providing presidential oversight of the Foundation's activities; the lack of this ability in the early Bush proposals was one reason for the delay in establishing the NSF. The Act, however, ensured that scientists would administer the funds, and in this regard established the process of peer review of research proposals that continues today.

In its first full year of operation in 1952, the Foundation's budget for research grants was $1.4 million with 28 research grants approved for funding.[10] The Foundation also established a fellowship program for predoctoral and postdoctoral students as part of its mission to ensure sufficient talent to both maintain and strengthen science research in the U.S. By the 2011 fiscal year, the overall budget for the NSF had grown to $6.81 billion, with $5.52 billion designated for research. The Foundation estimates that in the 2011 fiscal year greater than 214,000 people will be directly involved with programs funded by NSF, with millions impacted indirectly, with more than 7700 research grants approved for funding. [10]

The Role of Engineering Research at the National Science Foundation

The framers of the United States Constitution were silent on many issues contemporary of their time, but not on the issue of intellectual property. Through Article 1, Section 8 of the Constitution, which provides forms of protection for inventions and intellectual property of various kinds, the founders encouraged and supported scientific and technological development. They viewed science and technology (the useful Arts) as central to American success because it was, and still is, important to the economic success of the nation. Throughout the history of the

U.S., examples of “Yankee ingenuity” abound, and many of these examples in the early days of the country were motivated simply by the need to survive.

One of the most important technical advances made in early America was the American system of manufacture, in which goods were manufactured in large quantities at lower cost and with greater reliability. [11] The utility of manufactured goods consequently increased as did their diffusion into the general economy. In addition, an entirely new industry was created which relied on highly sophisticated and engineered machinery, and thus, created a demand for skilled workers.

The implementation of this system gave prominence in the United States to the field of engineering, defined as “the branch of science and technology concerned with the design, building, and use of engines, machines, and structures.” [12] The growth of the engineering field was marked by the introduction of formal education in engineering, culminating in an engineering degree by the late 1800s and early 1900s. As engineering education matured, it became less practice-oriented and more theoretical by incorporating topics from physical sciences and advanced mathematics.

Kilgore’s vision for a central science agency was one that would promote both science and technology (i.e., engineering) research to solve problems in society. Bush, on the other hand, while trained as both an electrical engineer and a physicist, advocated an agency that focused solely on basic science research. When the Bush plan became a reality in 1951, engineers pondered how to receive funding from NSF for their research activities—could engineering be considered a “basic science?” Engineers sought funding from NSF, promoting the necessity of engineering to implement the results of basic science research to provide usable goods for society. [7] Scientists, on the other hand, believed that this implementation was better suited for private industries. If engineering research was largely done by private industries, however, engineers were concerned that such research would not be done for the good of society but instead simply for financial gain.

In its founding, NSF was obligated by law to have four divisions, including the Division of Mathematical, Physical, and Engineering Sciences. For the 1952 fiscal year, when the research budget of NSF was $1.4 million, the total monies given to grants in engineering were just over $40,000, supporting three research grants from 96 applications. These grants and the few others in engineering sciences that were supported in the early years of the NSF were focused on research projects that could be described as more scientific than engineering in nature with no direct practical application. Indeed, from 1952 to 1957, grants in the engineering sciences accounted for approximately 8.5% of the total monies awarded to research projects. The small number of grants supported in engineering sciences during the early to mid-1950s led the American Society of Engineering Education to investigate allegations of discrimination at NSF against engineering, viewing it as an “applied science.” [7]

The differing viewpoints of scientists and engineers might have persisted longer except for one event—the launch of Sputnik by the Soviet Union in 1957. [7] The Soviet Union’s success in the “space race” gave credence to the belief that the U.S. was falling behind the Soviet Union in science and technology. In the year following the launch of the Sputnik, the overall NSF budget increased by 168% to $133 million in one year and funding for engineering research increased by 180% to $4.2 million. [7, 10] In addition, the Engineering Division (now Directorate) was later established in 1964 to support basic research in engineering science. Over the years, support of engineering at NSF has grown to include Engineering Research Centers (ERCs) and Science and Technology Centers (STCs). Today, the NSF Engineering Directorate has a budget for engineering grant awards that equal approximately 18% of the total NSF research budget, with additional monies awarded for engineering research from other NSF areas including the Computer and Information Science and Engineering Directorate and the Office of International Science and Engineering. [10]

Current Challenges for Science and Engineering

Now, as at NSF's founding, the areas identified by President Roosevelt as critical for maintaining the United States' pre-eminence as a global leader have not changed. STEM research continues to be vital to the economy and national security of the U.S. In addition, efforts to promote the development of STEM talent remain of critical importance, although these efforts are no longer restricted to higher education but now extend to K-12 education.

The National Academies Reports *Rising Above the Gathering Storm* [2] and *Rising Above the Gathering Storm, Revisited* [3] paint a rather bleak picture of the state of science and engineering in the United States, however. The National Academies, comprised of the National Academy of Sciences, the National Academy of Engineering, and the Institutes of Health, were asked by Senators Lamar Alexander (R-TN) and Jeff Bingaman (D-NM) to respond to the following: [2]

> What are the top 10 actions, in priority order that federal policy-makers could take to enhance the science and technology enterprise so that the United States can successfully compete, prosper, and be secure in the global community of the 21st century? What strategy, with several concrete steps, could be used to implement each of these actions?

It is important to understand why the senators posed this question. There was, and continues to be, broad national concern that the U.S. is falling behind other countries in the fields of science, technology, engineering, and mathematics. A review of the National Science Board report, *Science and Engineering Indicators 2010,* reveals that the global standing of the United States in science and technology is poor. [13] When the NSF was instituted, the Soviet Union and Germany were the primary global competition for the U.S. in the sciences; today, Asian countries are a threat. Consider, for example, the following:

- In the last three years the Global Competitiveness Index of the United States has dropped from 1st to 2nd to 4th (out of 139 countries) as ranked by the World Economic Forum. The top three countries in the 2010 – 2011 ranking are Switzerland, Sweden, and Singapore, respectively. The most troubling statistics are that the macroeconomic environment ranks 87th, that health and primary education ranks 42nd, and that the quality of math and science education ranks 52nd; [14]
- In 2008, 42 percent of the patents filed in the U.S. in information technology originated in Asian countries; [15]
- While universities in the U.S. awarded 52% of the doctorates in science and engineering worldwide in 1986, this percentage had dropped to 22% in 2003; [16]
- The United States ranks only 28th among developed countries in the proportion of students receiving science and engineering degrees; [17]
- More English-speaking engineers graduate from academic institutions in China than from in the U.S. [16]

In a talk at MIT, Tom Friedman, author of *The World is Flat*, commented that globalization “accidently made Beijing, Bangalore, and Bethesda…next door neighbors.” [18] It is clear that globalization has changed the role of science and engineering in the national economy. As World War II was the catalyst for a government research policy and the formation of NSF, and the launch of Sputnik was the catalyst for increased support of engineering research at NSF, globalization and its effect on science and engineering in the United States is now the catalyst for critical review of funding policies and STEM education, all in the context of improving the economy of the United States.

The Committee on Prospering in the Global Economy of the 21st Century, formed to respond to the Senator Alexander's and Senator Bingaman's questions, released the report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. This report recognized that *innovation*, specifically innovation in science and engineering, would play a large role in improving the economy in the U.S. On average, each job in a manufacturing industry supports 2.9 secondary jobs in related support businesses, and each job in a technical industry supports up to nine secondary jobs. [19] While increasing the number of jobs in science and engineering can have a large impact on the overall economy, of concern is that in 2007 just over 4% of the U.S. workforce was employed in science and engineering occupations. [20]

In *Rising Above the Gathering Storm*, four overarching goals were put forth in the areas of science and engineering research, economic policy, K-12 education, and higher education, with a total of 20 action steps for reaching these goals. Norman Augustine, the Chair of the Committee on Prospering in the Global Economy of the 21st Century, noted in remarks to Congress that the two highest priority goals were doubling the basic research budget in the physical sciences, engineering, and math, and increasing the number of K – 12 teachers with degrees in physical sciences, engineering, or math. [21]

The recommendations made in this report were ambitious, and required significant financial resources to be realized. This led to the passage of the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act of 2007, whose goal was "to invest in innovation through research and development, and to improve the competitiveness of the United States." [22] Notably, there was broad bipartisan support for this act, and with the recognition that it will take many years to accomplish the goals established in the 2005 *Gathering Storm* report, the COMPETES Act was reauthorized by President Obama in early 2011. [23] Much of the funding to implement the recommendations from the 2005 report was provided by the stimulus legislation of 2009 (American Recovery and Reinvestment Act, ARRA). [24]

In 2010, the authors of *Rising Above the Gathering Storm* assessed the impact of the recommendations made in the report and the subsequent passage of the America COMPETES Act with respect to the United States' competitive position in science and engineering. The conclusion reached in the new report, *Rising Above the Gathering Storm—Revisited*, was that the global standing of the U.S. had worsened, due in part to the continual increase in the national debt and the worsening U.S. economy. Interestingly, the authors note that other countries, including Canada, the United Kingdom, and Australia, implemented some the recommendations made in the 2005 report.

In this context, we must return to the position statement in the 2005 report—that innovation would play a large role in improving the economy in the United States—and ask how to promote innovation in today's economic environment. Margaret Thatcher, an Oxford-trained chemist, recognized the importance of (basic) scientific research, a key component of innovation, in a speech to the Royal Society in 1988: [25] "The greatest economic benefits of scientific research have always resulted from advances in fundamental knowledge rather than the search for specific applications."

Today, the majority of basic research in science and engineering is conducted in universities and government research institutes, not in industrial labs. And, the majority of the funding for this research comes from the federal government; in 2008, the federal government provided 60 percent of the funding for all academic research and development expenditures. [26] It is clear that the government has been, and will continue to be, the primary source for basic research funding. What is troubling is that the annual federal funding for research in the physical sciences, engineering, and mathematics is now equal to the increase in the U.S. healthcare costs every 9.5 weeks. [27] In addition, as a fraction of the GDP, the federal funding available for physical sciences research decreased by 54 percent and for engineering research decreased by 51 percent from 1970 to 1995. [16] With the increasing national debt and the uncertainty in the economy, a problem that cannot be ignored is how to double the financial support for basic research in this economic climate.

While innovation costs money, it takes people to innovate. Much concern has been voiced in the academy about the national shortage of students pursuing STEM careers. A particularly troubling statistic derived from a longitudinal study from Rutgers University researchers is that STEM retention rates from high school to college to post-graduation have decreased for the highest performing students over the last two decades. [28]

One reason for the declining retention rates is the lack of preparation of high school graduates for college-level science and math courses. The ACT *Condition of College and Career Readiness Report* estimates that only 45 percent of the students meet the readiness benchmark level in science and only 30 percent of the students meet the readiness benchmark level in mathematics.[1] [29] In addition, 15-year-old students in the United States rank 21st in science and 25th in mathematics on international standardized tests among developed nations. [30] One contributing factor to these statistics is the educational training of elementary and middle school teachers. In the U.S. in 2004, 60 percent of public school students in fifth grade were taught mathematics and science by teachers without a degree or certificate in mathematics or the physical sciences, respectively; in 2007, when these students were in eighth grade, only 20 percent of the students taught mathematics and science by teachers without a degree or certificate in mathematics or the physical sciences, respectively, primarily due to the changes brought about by No Child Left Behind. [31] To improve the preparation of high school graduates for college-level math and science courses, it is necessary to ensure that teachers in both the primary and secondary schools have degrees or are certified in their fields.

Led or Be Led

Today, we find ourselves in what Kleinman calls a “crisis of competitiveness.” [4] Globalization has altered the standing of the United States in science and engineering. In areas where we recently led other nations, including automobiles, energy production, higher education, and industrial research and development, we are now tragically far behind. Consider, for example, that Toyota now sells more cars in the United States than Chrysler and that five of the ten best-selling vehicles in the U.S. in October 2011 were foreign models. [32]

Those who worked to create NSF and other government agencies that provide funding for basic research recognized the importance of science and engineering to the national economy. At the time when NSF was founded, the threats to the economic wellbeing of the country were

[1] Students meeting the readiness benchmark, corresponding to a minimum score on the ACT subject area tests, have 50 percent chance of obtaining a B or higher or about a 75 percent chance of obtaining a C or higher in corresponding first-year, credit-bearing college courses.

mainly military. Today, however, the threats are mostly commercial. Countries whose populations dwarf that of the U.S. are devoting tremendous resources to shoring up their science and engineering infrastructure and human capital.

The problems that the United States faces are deep: Our educational infrastructure is failing and our culture has become consumer-based rather than production-based, all with a concomitant national loss of interest in science and engineering. We are in danger of being a post-World War II England.

So, we end with a question: Will we make the necessary investments in education, research, and infrastructure to reverse our current course, or will we continue a slide into a world where our economic future hinges on what other countries decide is best for us?

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