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The scientific enterprise has thrived in the United States. For three quarters of a century, American scientific productivity has been the envy of the world. Students from across the globe flock to American universities to take part in advances in every scientific discipline; American researchers in physical, biological, social, and behavioral sciences win international prizes and awards. Medical treatments and improvements in communication and transportation have extended and enriched lives, and products and processes emerging from public and private laboratories in the United States have revolutionized consumer, military, and social activities the world over. The fruits of scientific research in America abound, yet scientific thinking is not integrated into mainstream culture and politics.

Since the Second World War, generous financial support from the federal government to universities and research institutes for scientific research, as well as industrial investment in product development, have characterized the modern American scientific enterprise and made possible its achievements. The report *Science, the Endless Frontier* is recognized as the landmark document of this enterprise.

The author, Vannevar Bush, was the head of the White House's Office of Scientific Research and Development during the Second World War, and in that role had led the scientific effort that was widely recognized as having made Allied victory possible.[1] Large coordinated groups of scientists funded through government contracts and guided toward identified goals had produced an array of astonishing accomplishments—from transfusable blood plasma, population quantities of antibiotics like penicillin, and DDT and anti-malarials to prevent insect-borne illnesses, to radar, high-performance aircraft, proximity fuses for detonating munitions, and the atom bombs that would ultimately bring the war to a close. Bush oversaw this large and successful research and development enterprise as Roosevelt's informal science adviser and "Czar of Research."[2] As the end of the war came into view, he was one of many political and academic leaders contemplating how Americans could continue to reap the benefits of scientific research in peacetime. In late 1944, he received a request from Roosevelt to prepare a report that, he hoped, would lay the foundations of a lasting American science policy.

Written using input from dozens of prominent scientists and engineers, the resulting report was delivered to President Truman in July 1945, following President Roosevelt's death. As Bush wrote in the report, there had never before been a "national policy" to assure scientific progress. There was a deep respect in American culture for scientific empirical thinking and practical technology, and there had been government sponsorship of world-renowned scientific work from the Lewis and Clark expedition to military and civilian advances in geology, agriculture, medicine, astronomy, physics, and many other areas. But there had never been a central effort to support the broad scientific enterprise, nor a comprehensive appreciation of what science could contribute to American social and political advancement.

Science, the Endless Frontier presented an inspirational utilitarian vision of what science can bring to people. Invoking a classic theme in American culture, Bush wrote in his letter of transmittal, “The pioneer spirit is still vigorous within this nation. Science offers a largely unexplored hinterland for the pioneer who has the tools for his task. The rewards of such exploration both for the Nation and the individual are great. Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress." Welcomed by the scientific establishment, the report called on government to promote and support scientific research—especially basic research—and for a new independent national agency amply funded to oversee all research, military and civilian, biological, medical and physical, basic and applied, theoretical and experimental. It would ensure stable funding for long-term contracts and freedom of inquiry for scientists, and it would have the responsibility for the education of scientific specialists. In 1950, after years of debate, Congress would pass the National Science Foundation Act to create "a national policy for the promotion of basic research and education in the sciences," and to support through grants and contracts "basic scientific research in the mathematical, physical, medical, biological, engineering, and other sciences."

Science, the Endless Frontier is now known as the "seminal report" on American science policy,[3] hailed for leading to the "American postwar consensus" for the support of science,[4] and "one of the most influential policy documents in the nation's history."[5] Although various other individuals and organizations also influenced the emerging federal policy for science, the Bush report precipitated the debate that led to an unwritten policy that fostered decades of astounding progress of science. To consider the scientific landscape today one could well begin with an appreciative reading of the Bush report. Many of the issues raised are, in one form or another, still with us. The outcomes it shaped have both contributed to the brilliant scientific enterprise we see today and also cast shadows that our present moment has thrown into sharp relief. They deserve a closer look from today's perspective, to consider again what society needs that science could help to provide.

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In *Science, the Endless Frontier* Bush laid out a strong, specific vision for the role of science in society that today receives at least partial credit for shaping several essential aspects of our modern scientific enterprise and how it functions. This vision was founded in several core ideas that informed Bush's recommendations and the apparatus that eventually emerged from the ensuing debate and legislation.

Most basically—and perhaps most famously—Bush made a powerful case that "scientific progress is essential," and without it "no amount of achievement in other directions can insure our health, prosperity, and security." Advances in science, Bush argued, could offer far-reaching benefits to individuals and to society as a whole, including "more jobs, higher wages, shorter hours, more abundant crops, more leisure for recreation, for study, for learning how to live without the deadening drudgery which has been the burden of the common man for ages past." He therefore declared "science is a proper concern of government," and that government should be organized to assure scientific progress.

Bush—an engineer by training—ultimately had in mind a particular sort of progress: technologies to meet the material needs of Americans. Bush's penchant for practical application suffuses the *Endless Frontier* report and his other writings. Much of his career involved the invention and development of electronic and mechanical devices. The same month Bush sent his report to the President, his magazine article entitled "As We May Think," which to some is even better known now than *Science, the Endless Frontier*, forecast in detail a practical device we now know as the personal computer.[6] To Bush, government support of research was essential to public welfare because, as he asserted, it would produce medical cures, computing machinery, jobs, weapons, and "better and cheaper products" like "air conditioning, rayon, and plastics."

Specifically, Bush advocated for the government to support basic research—that is, in Bush's words, a search for foundational knowledge "without thought of practical ends." He maintained that basic research fills the well "from which all practical knowledge must be drawn" and is the force that drives the entire process of research and innovation. "New products and new processes do not appear full-grown," he argued: "They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science." Ever since *Science, the Endless Frontier* Bush has been known as the champion of basic research, and the concept has been attributed to him of a metaphorical assembly line where the output of basic research passes through the process of applied research and then development and finally to human use. This idea has influenced much of federal funding up to the present. Although the report did not actually illustrate research and development with a one-dimensional line, Bush nonetheless clearly shared this common view. Basic research was valuable to Bush *because* it would drive the process toward tangible and practical outputs to meet all national needs.[7]

The Bush report located this research primarily in colleges and universities, to be conducted by trained scientists—the "small body of gifted men and women who understand the fundamental laws of nature." During the Second World War, Bush, with funding through the research agencies he headed, had shown that universities could produce powerfully relevant work quickly, even military weapons and systems. Placing research in universities made it possible in his post-war plans to greatly increase government funding without a proportional increase in the size of government. Bush was tolerant of national labs but had a low opinion of research directed by the military. Recommending that universities host the research was his hedge against both large government and science directed by the generals. In Bush's view, research was done better by the "voluntary collaboration of independent men." In universities, he saw a unique setting where "scientists may work in an atmosphere which is relatively free from the adverse pressure of convention, prejudice, or commercial necessity," provided with "a strong sense of solidarity and security, as well as a substantial degree of personal intellectual freedom."

Bush believed strongly that science should be guided by scientists. As presented in the report, his plan granted the scientific establishment the authority to choose what scientific projects to undertake. The new agency he proposed was to be overseen by a board of distinguished scientists, and the director was to be chosen by those representatives of the science establishment.

This was a critical part of his vision—in a sense, the defining one, but at the time Bush prepared *Science, the Endless Frontier*, his was not the only vision on the table.

Almost two years before, Senator Harley Kilgore, a first-term Democratic New Dealer from West Virginia, had introduced legislation "to create a central independent agency of government devoted exclusively to the progress and expansion of science and technology, first to win the war and later to contribute to the peace."[8] The proposed agency would coordinate all government research activities. Kilgore compared such strong government centralization and planning to public control of water and power systems, public schools, and public lands, all of which he regarded favorably. At the time, Bush had come out against the bill, believing that research should have no government "command and control" after the war.[9] Bush's aversion to Kilgore's legislative approach, which was gaining support, and his belief that research is more productive under control of scientists themselves led him to write the report.[10] Soon after the Bush report, Senator Kilgore had a full legislative plan for a national program of scientific research.[11]

The structural similarities between Kilgore's plan and Bush's were greater than the differences. Both men thought science was greatly underappreciated, underfunded, and uncoordinated in different parts of the government and scattered universities; both wanted a central funding agency that would encompass military and civilian research, would foster education and disseminate science throughout the country, and would assess and coordinate the research being done in the country's universities and institutes.[12] But the differences in their plans were philosophical more than they were administrative, and therefore fundamental. It was a debate about how science thrives and what its relationship to society should be. Bush's plan was predicated on autonomy for scientists, aiming to provide them with independent leadership drawn from prominent universities and complete freedom of inquiry in choosing and pursuing their research queries. Kilgore, at heart a populist, advocated a system that would be more accountable to the larger society, with an agency governed by a committee consisting of ordinary citizens, labor leaders, and educators as well as scientists, and a director, not necessarily a scientist, appointed by the president. He wanted research to address directly the nation's social and economic needs, and he wanted funding deliberately distributed around the country. Patents from the research would belong to the public. In short, Kilgore wanted an agency closer to the political processes so that it could be guided by people's perceived needs, while Bush wanted an agency more expert-driven and insulated from the kind of public control that liberal political circles advocated. This difference is illustrated by their different attitudes to social science. Although Bush envisioned a comprehensive agency overseeing all science, he excluded social and behavioral sciences, believing the social sciences were in practice too closely associated with politics and government. Kilgore took the opposite position.[13]

The debate continued in Congress and in the science community for years. Reverberations of the debate persisted for decades in policy debates in the United States and in ideological debates of the Cold War.[14] However, by 1950 the National Science Foundation Act established that the agency would be overseen by a board of distinguished scientists. The legislative outcome did not provide exactly for the arrangement Bush had called for. But today, the scientific community, usually within individual disciplines and often the researchers themselves, largely make decisions of planning, selection, and evaluation of research throughout universities and the government.

Following the report, a science policy emerged, though unwritten and imprecise. The federal government provided increasing funding to the National Science Foundation and other agencies. Federal agencies and professional associations tracked and touted scientific progress. Programs were developed for governing the thriving scientific enterprise. Congress created new committees. Science policy grew into a field of academic study. By the 1960s federal support for research and development had grown by more than 20 fold[15] from 1940, comprising nearly 2 percent of total economic activity.

The investment by the public and private sectors in scientific research and science education since 1945—cumulatively in the trillions of dollars[16]—has returned large benefits in medical cures and extended lives, increased economic productivity, eagerly received consumer and professional conveniences, and military power—just as Bush projected. Federal funding has supported an astonishing explosion in our knowledge about every aspect of our universe, world, and human physiology, society, and psychology. To choose a few examples out of hundreds of thousands: Human traits, at first thought to be a straightforward expression of inherited parental DNA, have been shown to be influenced epigenetically by parental environment. Astrophysicists have observed colliding neutron stars creating the heavy elements we find on Earth. Macroscopic quantum entanglements have produced simultaneous changes in systems widely separated from each other. Gun violence has been characterized on epidemiological and psychological grounds. Geoscientists have explained how movements of tectonic plates carry biological carbon compounds and organisms deep into the Earth. Irrational economic behavior and human implicit biases are recognized, categorized, and predicted. Individual brain cell activity can be observed instantaneously as creatures think and process stimuli. Emission and removal of carbon in the Earth's atmosphere is understood in detail. The public has had a vague notion of the creativity, beauty, and power of these advances and has wanted them to continue.

Yet the commitment to increasing federal funding—the large piece of the Bush implicit policy bargain—could not be sustained. From 1968 to 1971, as costs of the war in southeast Asia soared, federal research spending fell 10 percent (in inflation-adjusted dollars) with spending designated for basic research falling even more (by 18 percent from 1967 to 1975). Today federal spending for research and development (R&D) is less than 40 percent of what it was in the 1960s, as a percentage of the gross domestic product. Spending on R&D in industrial corporations has grown, keeping the overall spending at approximately 2.5 percent of gross domestic product (GDP) since 1968.[17] But as Bush had pointed out, corporate funding is almost entirely short-term and developmental, supporting commercially predictable outputs benefiting the investing corporation, rather than innovative research that anyone could build on. Compared with many other countries, the US investment in scientific research, once an international benchmark, has not kept pace. At least seven other countries surpass the United States in public R&D funding as a percentage of domestic economy. Scientists, seeing federal funding, though large, as far less than optimal, continually lobby for more funding. There have been occasional spurts of support—for example, in connection with the space race and the Apollo program in the 1960s, the biomedical boom and doubling of the budget of the National Institutes of Health two decades ago, and the 2009 economic stimulus. It remains to be seen whether recent proposals for increased R&D budgets, such as the conveniently named Endless Frontier bill, will be realized in the federal appropriations process. In any case, although the federal funding of R&D is much less than could be spent productively, the post–Second World War commitment to funding of science changed the landscape for science permanently.

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Nevertheless, there is reason to ask: Is science providing all it should, and are citizens receiving what they need from science? Bush wrote that scientific progress was essential in the war against disease and could improve public health—yet a thriving scientific enterprise has not prevented millions of people from putting their children at calculable risk by failing to get vaccinations. Nor has the scientific progress been enough to prepare the United States to deal with a major virus pandemic in 2020. And it has not resulted in the United States undertaking the corrective measures required to stem costly climate change.

Evidently, our scientific enterprise is failing to give citizens some important things they need. These have not been failures of research—in immunology, virology, epidemiology, oceanography, or atmospheric science. Rather, they have been failures in the relationship between science and the public—something that the Bush report and subsequent debate largely overlooked.

From the modern perspective, in this regard Bush turns out to have been somewhat shortsighted. In the belief that scientific progress ultimately relies on the freedom of scientists to pursue basic research without thought of practical ends, he promoted a system that—while helping research to flourish—has also had the effect of distancing science from the public, and vice versa. His goal was to ensure not only rational, stable funding for scientists, but also the freedom to do their chosen work, unencumbered by societal direction or governmental planning.[18] While his competitor Kilgore had proposed an arrangement for all science funded by the government to be "a true servant of the people,"[19] what has resulted can be seen to be more a servant of the scientists—a system to fund work that scientists themselves choose to do.

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Indeed, many scientists are convinced that they would lose scientific creativity and effectiveness if they focused where the public might ask, rather than where their trained curiosity and established research avenues take them. In my career as a research scientist and as a policymaker serving in Congress for sixteen years I have observed that scientists fiercely guard their prerogative to choose the research agenda. Though they will make some allowances in order to secure funds, they generally believe that the fruits of their independent investigations will accrue best to the public without explicit public guidance. Research grants, usually awarded through scientific review, tend to be concentrated along elite, established patterns. The scientific community, as they have sought to avoid constraints that might come from government planning, have asserted independence in a way that results in the public regarding science as beyond their ability to judge or control, or sometimes even to understand—much less participate in.

Bush called for access to higher education and scientific training to be established through a scholarship program with the goal of "encouraging and enabling a larger number of young men and women of ability to take up science as a career." This idea of select, trained researchers as the embodiment of science is reflected in the current practice of science and science education, as well as in public attitudes toward science. Researchers and their funders typically see their job as exclusively to do research. Even now most programs in science education still focus primarily on identifying and training future professional scientists and engineers, commonly called "filling the pipeline."[20] When legislators speak of our science teaching, they commonly allude to Americans' comparative disadvantage to rivals in the number of scientists and engineers.

The result is that the public sees science not as a comprehensible approach toward understanding available to them, but rather as what researchers do in their inaccessible labs. They see scientists as people who have mastered complicated ideas and instruments unfathomable to nonscientists. Products, cures, and other material benefits may emerge from research, after several unseen steps, and the receiving public has little understanding of how they came about. They see little place for themselves in science, and although they welcome practical products that emerge from the scientific enterprise, they see little place for science and scientific thinking in their lives. This presents a problem when many of the world's most urgent challenges, for example, pandemics or climate change, desperately require the public to engage with science and also to build an understanding and trust of scientists and scientific work. If members of the public think science is not intended for them, they turn away. They may not recognize situations where scientific input can help them fulfill their civic functions. They may not ask for verification of information given to them.

At the root of the issue is a limited view, traceable in part to Bush's report, of what science is and how it contributes to society. In *Science, the Endless Frontier*, Bush identified science with research and development, and its benefit to society with its more or less tangible outputs: technologies, medicine, products. But there is more to science than research, with its specialization and sometimes esoteric techniques, and the tangible outputs are only part of what the public should obtain from the science bargain and only part of what they should think of when they think of science. In its essence, science is a way of asking questions that leads to the most reliable knowledge about how things are. This is its most essential contribution.

Months before *Science, the Endless Frontier* was issued, the American Association for the Advancement of Science's Committee on Science and Society offered a more expansive, philosophical view of the place of science in a republic. The committee began, as would the Bush report a few months later, with the assertion that science is essential. The committee took a different tack in explaining how science is essential. They represented the idea, coming out of the Enlightenment, that science can have great social and political usefulness as a way of thinking. The committee declared that "a research policy is . . . as necessary to our survival as a foreign policy and a defense policy," and that the place of science in a modern government is "no less than [that of] the law and the courts." From the observation that the "discrepancy between our advanced technology and established practices and organization is one of the major threats to our free, democratic social order," the Committee continued that scientists must "build public interest into their research." The Committee on Science and Society summarized, "A policy for research and an understanding of the relation of science to society is more than a question of gadgets and even technology." It is "not a program of planning and control" but "a declaration of purpose . . . to use the instruments of critical thinking and trained organized intelligence" to strengthen "our free, democratic social order."[21]

This view did not dominate in the policy debate emanating from *Science, the Endless Frontier*. In the years after his report Bush challenged the idea of a definable and teachable scientific method that could be used outside of the laboratory by nonexperts. He recommended that, rather than trying to prepare the nonscientific public to apply critical scientific thinking to public problems, the country should put more highly talented scientists to work in research that ultimately would benefit the public.[22] While the array of material benefits from scientific research has been a rich return to society, this bargain is limited. Beyond passive public receipt of products and cures from science, we need a much greater engagement of the public with science—in both directions. We need more public guidance and oversight of science, and we need more public use of scientific thinking in public affairs. This requires action on the parts of both the public and the scientific community.

The stakes of this issue have been amply, and tragically, illustrated by the coronavirus pandemic surging in 2020. For decades previously, scientific experts had been writing alarming articles about the devastation likely from emerging diseases and about the need for public health preparations. Yet America was not prepared. In both the long term and the short, policymakers failed to provide for adequate testing, medical equipment, and trained personnel. The public had failed to demand them. The public and their policymakers generally were slow to comprehend and adopt recommended measures like social distancing or the wearing of masks. For their part, scientists had also failed to pursue some avenues of research needed to combat the virus. Given the freedom to set their own priorities, virologists undertook molecular analysis of the structure and replication of viruses, yet some of the most relevant research about viral transmission—research more connected to society at large—remained neglected. Neither the virus researchers nor the policymakers fully integrated social sciences into their thinking about possible outbreaks and consequences. Policymakers and the public had not insisted on having a part in setting the research priorities. There are many lessons to be drawn for a national science policy, the greatest of which is that a well-funded and trained cadre of scientific researchers is no substitute for an informed, engaged public. This lesson extends far beyond the example of the pandemic.

Funded research has thrived, but public evidence-based thinking and the public ability to act with comprehension on scientific evidence has not grown alongside the growth of research. Providing funding for research and allowing scientists to spend the money to pursue the activities they choose is considerably easier than applying research findings and scientific decision making to public issues. Most legislation and policy decisions have components that can be improved by incorporation of scientifically verified information. Frequently, that information is not incorporated well, or at all. It is not enough to have some scientifically trained staff in policy-making and regulatory agencies. In matters of transportation, communication, migration, ag-

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