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Science Institutions for a Complex, Fast-Paced World

The post-World War II model for organizing science remains powerful, but moving beyond its limits will be necessary for assuring the contributions of science to solving a wide array of societal challenges.

The story of Vannevar Bush and his 1945 report, *Science, the Endless Frontier*, has attained in a mere 75 years something of the status—at least among those of us concerned with American science and technology policy—of Moses delivering the tablets from Mount Sinai. The narrative elements are almost mythically compelling: how Bush mobilized the academic science community to deliver the technological advances that helped the United States and its allies win World War II; how, with victory in sight, he recognized the need for a continuation of government support for academic science to ensure America's continued military and economic security after the war; how President Roosevelt—at Bush's behest—requested a plan for postwar science; and how Bush in response delivered *Science, the Endless Frontier*, the brilliantly articulated rationale and blueprint for an implicit social contract between government and the science community.

As with the Moses story, there were bumps along the way—for example, when President Truman vetoed the bill to establish the new science funding agency that Bush had proposed because it lacked provisions that would assure democratic accountability. Yet in the end, the core principles enshrined in *Science, the Endless Frontier* are those that have guided both the politics and policy of government support for science in the postwar era: First, that new knowledge was an essential ingredient for assuring a safe and prosperous future. Second, that the most important source of such new knowledge would be academic scientists freely pursuing their curiosity about nature wherever it might take them. Third, that an appropriate and essential role for government therefore was to provide support for academic research. And fourth, in fulfillment of the social contract, that the support thus provided by government for undirected academic science would be more than repaid in future benefits for society.

These precepts have underlain an extraordinarily robust political consensus in the United States about the importance of government support for science. For this reason, they have also continued to guide the development and growth of core science institutions, both the government agencies that provide funding for science, and the uniquely American system of research universities that Bush viewed as the rightful performers of unfettered knowledge creation for long-term social benefit.

Yet it is also obvious that the nation has, in many ways, evolved beyond the foundations that *Science, the Endless Frontier* established. Certainly the very size and complexity of the research enterprise is beyond anything that Bush imagined. More important, the nation has benefited from its investments in science in complex and

diverse ways far beyond anything that could have been imagined when Bush laid out the design principles for a publicly funded research system. Not to belabor the obvious, but today's understanding of how knowledge, innovation, economic growth, and social change are all intimately interdependent is something of which Bush—and his world—had barely an inkling. In the past 75 years, the challenges—from nuclear proliferation to climate change to wealth concentration to social media's impact on expertise and truth—that have resulted, at least in part, from society's application of scientific advances are now subjects that science itself must directly help to solve.

What do these changes demand from institutions of science? Here we draw on our perspective as leaders of two very different institutions—and as partners in the publication of this magazine—to sketch out some elements of a vision of how our own institutions are evolving to meet the challenges of the next 75 years.

The National Academies: authoritative and nimble

Although there can be no single institution representing all of science, it would be fair to say that the National Academy of Sciences' principal underlying responsibility is both to project and protect the authority and trustworthiness of science as a whole. NAS has been advising the federal government since it was granted a congressional charter signed by President Lincoln in the midst of the Civil War. By the time Vannevar Bush delivered his report in 1945, the NAS had just completed major contributions to the nation's World War II efforts by advising on the Manhattan Project, antisubmarine warfare, and other science-related projects that helped lead the Allies to victory. However, demand for its advice quickly grew well beyond the physical sciences and national security needs. In the following decades, the National Academy of Engineering and the National Academy of Medicine (formerly the Institute of Medicine) were founded, and today, all three operate together as the National Academies of Sciences, Engineering, and Medicine to provide independent, objective advice to the nation whenever called on to do so, per the mandate in the original charter.

Advances in science and technology remain major drivers of US growth and prosperity, and worldwide, the nations that have invested in science have proven to be the most able to elevate a large fraction of their citizens rapidly out of poverty into the middle class. In fact, science and technology are arguably more critical to national security, economic competitiveness, and quality of life now than when *Science, the Endless Frontier* was released. Therefore, it is as important as ever that the National Academies deliver the type of salient, forward-looking advice that Vannevar Bush delivered, and that the government factors that advice into decisions about policy.

But in today's world, the National Academies can no longer rely on a business-as-usual approach if we hope to help shape policy with science and the evidence it can provide. We are operating in a rapidly changing policy environment that demands timely advice that decision-makers can act on. Support for research funding remains strong, but in these times of polarizing partisanship, science itself can become politicized. Scientific literacy remains low across the nation, misinformation is easily proliferated and amplified, and expertise is distrusted in some sectors. The Academies are currently undertaking strategic planning to address the challenges confronting science-informed decision-making in the twenty-first century. The ultimate goal is to become a more nimble institution—one that still delivers the authoritative advice for which the Academies are known, but in ways that are much more relevant and responsive to the needs of policy-makers and the public.

For decades, it was considered sufficient for the Academies to conduct a consensus study and deliver policy advice through a report to the federal agency that sponsored it. But these reports often have implications that range far beyond a single agency. Other stakeholders include those who are directly affected by possible policy or regulatory actions, the commercial sector that might stand to profit or lose from such actions, state and local decision-makers, and other members of the public. The Academies must embrace new technologies and new modes of communication to reach these broader audiences.

Moreover, the Academies cannot simply take public trust in science for granted. The National Academy of Sciences, in particular, has an obligation to ensure that science is worthy of the public's trust by leading efforts to improve the culture and practice of science, and the integrity of the research enterprise. We also need to communicate to the public how the norms of science allow researchers to build confidence in their findings, and ultimately to help the public develop better capacity to discern which results are trustworthy. In addition, the Academies have a responsibility to speak up and defend science when it is being politicized, ignored, or maligned. Increasingly, we are engaging in new ways of communicating directly with the public about the evidence around vaccine safety, climate change and extreme weather, the economic and fiscal impacts of immigration, the safety of genetically engineered food, cybersecurity, and other issues that feature prominently in public discourse.

Beyond publish-and-distribute

In addition to expanding to whom the National Academies communicate, the timing of communication must also evolve. The tradition has been to disseminate findings and recommendations from consensus reports at the time a report is released, and then move on to the next project. A more effective strategy would be to continue to share and reinforce findings and recommendations from Academies' reports whenever world events bring the issue into the public spotlight, as long as the advice is still current, and to invest in follow-up activities to increase the chances of effective incorporation of the recommendations into policy.

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Toward that end, the Academies have created a new model—the action-collaborative—to help ensure that reports have lasting impact long after publication. For example, after completing a landmark report on sexual harassment of women in the academic sciences, engineering, and medicine, the Academies convened the Action Collaborative on Preventing Sexual Harassment in Higher Education. The collaborative brings together leaders from more than 40 academic institutions to work toward targeted, collective action on addressing and preventing sexual harassment across disciplines and among all people in higher education.

The National Academies are also examining new strategies for delivering the type of real-time solutions that policy-makers often require. The Academies' longstanding reputation for independence and objectivity translates into an unparalleled ability to convene renowned experts, sometimes at a moment's notice, to advance solutions around critical challenges facing the United States and the world. For instance, when the rapid spread of the mosquito-borne Zika virus in Brazil and its presence in more than 25 countries raised concerns about US outbreaks, the Academies quickly organized a workshop to allow leading researchers to exchange ideas and insights, and participants identified basic research priorities that could be implemented quickly to help minimize the likelihood of local Zika virus transmission in the United States.

The National Academies must also evolve to better reflect the collaborative, multidisciplinary nature of today's science. Indeed, the seminal 2014 report on convergence science—research that crosses disciplinary boundaries, integrating tools and knowledge from the life sciences, physical sciences, engineering, and other fields—has prompted universities and research institutions to restructure their approaches to research. The Academies are trying to incorporate its own advice by working across disciplines and divisions to address pressing, cross-cutting issues such as climate change and environmental health. The Academies are striving to create a more agile organization that can integrate seamlessly the intersections of human, machine, and natural-world aspects of current issues.

Worldwide, scientific capacity has been increasing, and many nations hold scientific expertise relevant to problems that the United States is addressing. Not only is the research enterprise becoming increasingly global, but it is probably accurate to say that there are few problems, however novel they may seem in one place, for which there is not relevant experience and expertise among scientists somewhere else on the globe. The National Academies have a long tradition of working with other top-level science organizations around the world to address shared concerns, but better ways are needed to collaborate and share relevant knowledge and expertise, especially for issues that cross national borders. To that end, with the discovery of the revolutionary new gene editing technology CRISPR-Cas9, the Academies recently convened two international summits on the emerging field of human genome editing that drew widespread global audiences. The Academies are currently following up those efforts, alongside the United Kingdom's Royal Society, by serving as the secretariats for an international commission tasked with developing scientific and technical standards and requirements that must be met for any potential clinical application of heritable human genome editing.

Here in Washington, DC, the National Academies are navigating the fractious political environment by continuing to maintain strong relationships with the executive branch, including with the White House Office of Science and Technology Policy. Academies' representatives regularly brief members of Congress and their staff on new studies, and are often called on to provide expert testimony at public hearings.

Over many decades, the National Academies have earned a stellar reputation for delivering the "gold standard" in independent, evidence-based advice. The commitment to that ideal will never waver. But just as the world—and science itself—is constantly evolving, the

Academies too must change to remain relevant. The Academies' vision for the next 75 years is ambitious, but making these reforms is crucial if this venerable and essential science policy institution is to continue to fulfill its mission as trusted advisers to the nation as a whole.

Research universities: innovative, inclusive, embedded

Science, The Endless Frontier imagined universities as the driving force behind American progress in the postwar era. "They are the wellsprings of knowledge and understanding," it declared. "As long as they are vigorous and healthy and their scientists are free to pursue the truth wherever it may lead, there will be a flow of new scientific knowledge to those who can apply it to practical problems in Government, in industry, or elsewhere."

But this argument was merely the necessary foundation for the policy argument that Bush wanted to make: "If the colleges, universities, and research institutes are to meet the rapidly increasing demands of industry and Government for new scientific knowledge, their basic research should be strengthened by use of public funds."

As obvious as both ideas are now, they would have been unfamiliar to most policy-makers and citizens—and even many scientists—in 1945. Indeed, the modern comprehensive research university didn't begin to take on anything like its current form until the late nineteenth century, with the creation of a number of new, research-intensive universities, most notably Cornell, Stanford, Johns Hopkins, and Chicago. According to *Science, the Endless Frontier*, total research expenditures by all US universities was a mere $30 million when World War II broke out. And the total number of universities that were home to world-class research across multiple scientific disciplines at the time was perhaps less than 20. Most of that research prior to the war was supported by industry or philanthropy.

So envisioning universities, funded by public research dollars, as the dynamo that would power the nation into the unforeseeable future was an act of considerable vision and imagination on the part of Bush and a small group of his peers from the top academic institutions at the time. Unquestionably, the nation's current system of highly research-active universities today—now grown to perhaps 200, depending on how one defines them—is the direct progeny of the policy model that Bush laid out so compellingly in his report. We don't need to say more about how important they have been for the well-being of science, the nation, and the world, in the past 75 years.

But they were designed in another time, for another time. In some ways, research universities have proven remarkably able to adapt to a changing world. At the end of World War II, academic science was rigidly disciplinary, its basic operational unit was the individual scientist, its concerns largely those of pure discovery, and its scale limited by the relatively small size of the academic research community, the small number of research-intensive institutions, and limited funding. Today's academic science enterprise is increasingly inter- and multidisciplinary, its work typically carried out in teams and centers and institutes, by tens of thousands of top-tier scientists in hundreds of universities across the nation, directly engaged with problems of immediate human import, supported by public funding measured in tens of billions of dollars per year. Along these dimensions, the enterprise has evolved beyond anything Bush might have imagined, adapting to the world that it helps to continually remake.

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And yet in other ways, the design criteria enshrined in *Science, The Endless Frontier* are now an obstacle to meeting the promise of widespread public betterment that Bush asserted. The model of the elite, insular university, serving only the best and brightest and contributing—through its scientific discoveries, and by training the next generation of best and brightest—to progress that benefits everyone, turns out to be a deeply incomplete, even impoverished foundation for carrying out science and training the next generation of scientists and citizens in the coming 75 years.

Hybrid vigor

The growing concentration of wealth, health, learning, and opportunity among an increasingly small proportion of American society lies at the heart of today's greatest challenges. The nation can neither heal its political and socioeconomic wounds, nor contribute decisively to putting global development on an equitable and sustainable trajectory, without redressing these imbalances. As a cultural matter, the limited view of the university enshrined in *Science, the Endless Frontier*

descends directly from the classical tradition of the insular, rarified institution of higher learning—the Platonic Academy—made modern through the pursuit of modern science. For the next 75 years, universities will need as well to embrace more recent, homegrown traditions, rooted in the creation of the American land-grant university in the mid-nineteenth century, designed to serve the knowledge needs of an agrarian society, and the philosophic tradition of American pragmatism, which views the pursuit of knowledge and truth not as the domain of the elites but as deeply entwined with the practical experience of daily life.

This hybrid vision demands that excellence and social embeddedness will have to be fused in the nation's universities to achieve public value. World-class knowledge production and cutting-edge technological innovation must be pursued in institutional cultures dedicated to greater accessibility and reflective of the socioeconomic and intellectual diversity of the nation. Universities will have to not only integrate comprehensive liberal arts curricula with the cutting-edge knowledge essential to the workforce of the global knowledge economy, but do so for tens of millions more than its current capacity and ambition allow, so that the great majority, rather than the top few percent, can benefit from an economy increasingly based on the generation and application of useful knowledge. Indeed, inasmuch as access to knowledge underpins the societal objectives of a pluralistic democracy, scalability and thus accessibility must be at the core of evolving institutional models.

This vision is no more radical than the one offered by *Science, the Endless Frontier*. At that time, the need was to catalyze a system of research universities that could provide the knowledge foundations for national progress and well-being in an industrial society. The key ingredients were scientific autonomy at the individual level, and public money to support knowledge discovery. If results over 75 years have been stunning, new dynamics have come powerfully into play—as with any complex, adaptive system. Now the need is to advance research and education to enable broadly distributed benefits in the postindustrial world. The necessary ingredients are public purpose at the institutional level, and social partnerships, at scales from local to global, for knowledge coproduction.

Just as *Science, the Endless Frontier* built on the capabilities of a small set of elite research universities in 1945, so does the vision of the public-purpose university build on a small set of emerging universities that are serving increasingly large student populations from highly diverse backgrounds, working in partnerships with companies, governments, and civil society to create useful knowledge, while advancing discovery and innovation of the highest order. Arizona State University is irrevocably committed to this new vision, as are a handful of others, including Purdue and Penn State.

Your guide to the next 75 years

Our shared view is that the institutions of science—the ones that we lead, as well as the innumerable other important players in today's science and technology domain—are indeed moving toward new ways of operating that are appropriate to today's hyper-complex world, but in many ways they are also still tethered to the designs forged during the Cold War and rooted in *Science, the Endless Frontier*. This tension is necessary, because there is much that needs to be protected and preserved. And it is frustrating, because it hinders necessary change, often in the face of urgent challenges.

The negotiation of this tension requires active discussion, argument, experimentation, disagreement, among the wide range of stakeholders in the science and technology enterprise. And that is why our institutions are partnering to publish *Issues in Science and Technology*: to provide a place where complex and uncertain problems of science and technology policy can be presented, explored, and debated—and articulated in a manner that is fully accessible to decision-makers in government, industry, and academia, yet not in the least dumbed-down.

If the world of science and technology policy has in many respects moved beyond the substance of *Science, the Endless Frontier's* argument, we still look with awe at the clarity and brilliance of Bush's presentation, which galvanized the imagination of scientists and politicians alike, from the day it was first published. Seventy-five years later, perhaps the world has become too complex and contested for any such single view of science to take hold. But our hope is that *Issues in Science and Technology* can be the leading forum for powerful ideas and compelling options that improve the nation's ability to bring science and innovation to bear on the achievement of widespread peace, health, and prosperity. In that ambition we stand squarely on the shoulders of the vision articulated by *Science, the Endless Frontier*.

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