The National Academy of Sciences at 150

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On March 3, 1863, Senator Henry Wilson of Massachusetts rose in the Senate chamber to, as he told his colleagues, "take up a bill…to incorporate the National Academy of Sciences." He read two short paragraphs concerning membership and the obligation of the Academy to "whenever called upon by any department of the Government, investigate, examine, experiment, and report upon any subject of science or art." The Senate passed the bill by voice vote, and a few hours later, the House passed it without comment. Later that evening, President Abraham Lincoln signed the bill into law.

In the century and a half since 1863, the National Academy of Sciences (NAS) has grown from a small band of 50 charter members—each of whom was specified in the founding legislation—to an organization of more than 2,500 national members and foreign associates. In 1916, the Academy created the National Research Council, which today recruits thousands of specialists each year from the scientific and technological communities to participate in the Academy's advisory work. The establishment of the National Academy of Engineering in 1964 and the Institute of Medicine in 1970 resulted in a multifaceted institution that investigates issues ranging widely across the sciences, technology, and health. The charter members of the Academy, who met for the first time on April 22, 1863, in the chapel at New York University, scarcely could have envisioned what their fledgling organization would become.

To celebrate the Academy's sesquicentennial, the Arthur M. Sackler Colloquia of the National Academy of Sciences, with additional support from the W. M. Keck Foundation, the Ford Foundation, and the Richard Lounsbery Foundation, held a meeting in Washington, DC, on October 16–18, 2013, entitled "The National Academy of Sciences at 150: Celebrating Service to the Nation." The meeting began the evening of October 16 with the 2013 Annual Sackler Lecture by Daniel J. Kevles, Stanley Woodward Professor of History, History of Medicine, and American Studies at Yale University, who reviewed the first century of the Academy's history in the context of its dual mission to advance science and serve the government. Over the next 2 days, eight groups of speakers examined topics where the Academy's advice has been especially consequential. On the first day, which was focused on science, politics, and policy, the speakers discussed national security and international relations, the International Geophysical Year and the space sciences, climate change, and biology in public policy. On the second day, which examined the nation's infrastructure in health, information, and education, the topics addressed were radiation hazards, biodemography and vital statistics, computing and information, and K-12 science education.

This supplement to the *Proceedings of the National Academy of Sciences* contains the edited spoken remarks of the presenters along with short introductions to each of the eight areas discussed. Free downloads of many of the reports mentioned by the speakers are available at www.nap.edu, and Webcasts of the colloquium are available on YouTube.*

The National Academy in the American Democracy 1863–1963

Daniel Kevles, *Yale University*

In 1863, Congress created the National Academy of Sciences, a private agency with the public role of advising the government on policy-related technical issues. The prime movers behind the action were Harvard's Louis Agassiz, a native of Switzerland and a brilliant student of rocks and fossils, and the geophysicist Alexander Dallas Bache, Benjamin Franklin's great-grandson, the head of the Coast Survey, and an authority on terrestrial magnetism. Agassiz, the academic, saw in a national academy an institution that would raise the quality of science in the United States by granting the imprimatur of membership not to men of mere learning but only to men of original scientific achievement. Bache, the longtime federal scientist, felt the need for an institution of authoritative scientists who would safeguard public policymaking in an increasingly technical age from charlatans and pretenders.

Like the French Academy of Sciences, which provided the model for the two men, the US National Academy would choose its own membership and be limited to 50 members. Agassiz, elected as the first foreign secretary, was thrilled, holding that the nation's men of science now had a "standard for scientific excellence." Bache was elected as the first president. During the 5 years of his administration, which ended with his death, in 1867, the Academy received 13 requests from the federal government for advice on topics ranging from assessments of weights, measures, and coinage to the insulation of ships' compasses from the influence of iron cladding and to tests for the purity of whiskey.

Agassiz and Bache had gone behind the back of their friend, the physicist Joseph Henry, to achieve their goal. A world-class authority on magnetism and the Secretary of the Smithsonian, Henry had opposed the creation of such an academy, suspecting that it might be considered "at variance with our democratic institutions" and might become "perverted…to the support of partisan politics." Henry was at first far from pleased, but he accepted membership in the Academy and, upon Bache's death, its presidency. He kept the Academy scrupulously out of politics, establishing the tradition that the Academy would not volunteer its services to the government. Perhaps this explains why during the 10 years of his term, the government made only two requests for advice.

The First Half Century

To put the Academy more in line with American democratic institutions, Henry obtained a removal of the membership ceiling so that five new scientists could be elected each year. Henry had come to think that an "intelligent democracy" could properly bestow

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honors for achievement, and the creation of the Academy had opened in America another "avenue for the aspirations of a laudable ambition."

For most of its first half century, however, a variety of circumstances militated against the Academy's fulfilling its twin goals of stimulating the development of American science and providing reliable scientific advice to the government. Although it was common for European academies to receive subsidies from their governments, the US National Academy, in its determination to avoid political corruption, sought and received none. Its financial resources were severely limited, insufficient to publish more than an occasional proceedings and obituaries of its members. The Academy met in the Smithsonian, having no headquarters of its own, and the meetings were poorly attended. Could an honorific body without resources have an impact on the life of American science? No, said Leo Lesquereux, a paleobotanist who had moved from Europe to the United States "In Europe, honor conferred is worth more than money, but in America the same honor is worth nothing by itself."

Then, too, alternative avenues were proliferating for the satisfaction of laudable scientific ambitions. The nation's scientific enterprise was rapidly expanding in tandem with the growth of the country. To meet the need for knowledge, federal science grew enormously, proliferating with agencies such as the Geological Survey, the Weather Service, the Forestry Service, the National Bureau of Standards, and the Department of Agriculture's multiple research bureaus and the experiment stations it supported around the country. Comparable and then even greater growth was prompted in the private and academic sector by what historians call the Second Industrial Revolution. This was the transformation that drew on the exploitation of the laboratory sciences to create new technologies and new industries—notably in electric light and power, communications, cinema, petroleum, and a myriad of other products of organic chemistry. A number of companies—notably G.E., AT&T, Westinghouse, and DuPont—established industrial research laboratories, enlarging the demand for technical expertise.

The demand called forth the beginning of what would prove to be a long exponential enlargement and diversification of the American scientific, engineering, and medical communities. The desire to understand and manage the new urban industrial order helped energize the growth of sociology, anthropology, and economics. Also, as the new disciplines grew, they organized, forming an abundance of specialized scientific societies in the half century after the founding of the Academy. All these societies happily bypassed the Academy, some deliberately. For example, the American Physical Society was founded in 1899 at the initiative of a physicist at Clark University named Arthur Gordon Webster. He resented the Academy, to which "few of us can hope to belong, and which we might not enjoy if we did." For Webster, as for scientists in other disciplines, their professional societies provided nonexclusive forums where scientists could hear papers by the leading members in their fields.

These developments undercut the Academy's twin purposes. Unlike the Academy, most of the specialized societies published journals, spun off local sections, and established systems of awards and recognitions, all of which made them a force in the disciplines they represented. Their members were enlisted by federal and state agencies to provide expert assessments on the multiplying issues of high-technology society, including, for example, conservation, the purity of food and drugs, and the regulation of the financial and industrial system. By the early 20th century, there were plenty of experts to provide similar services in the federal government's own agencies. Withal, the National Academy's advisory activities steadily declined. In the 10 years between 1879 and 1888, the Academy had received 10 requests for advice from the government. In the 23 years between 1890 and 1913, it received eight, including none in the 4 years after 1909.

In contrast to the collective panoply of the specialized societies, the Academy was relatively ill equipped to play a significant role in helping the federal government deal with the great questions involving science and technology then confronting the United States. Even though it had doubled the election of new members each year to 10, its exclusiveness continued to arouse resentment, with some nonmembers regarding it as "a menace to true democracy," to quote the observation of one of the members. It was largely disconnected from the Second Industrial Revolution, having repeatedly declined to admit engineers, even Edison himself, from the rise of the regulatory state, having no social scientists among its ranks, and from the mounting requirements of medicine and public health, having hardly any representatives of scientific medicine on its rolls. In the unhappy judgment of a biologist at Princeton, the membership generally preferred to continue as a mere "blue ribbon society."

The Coming of War

George Ellery Hale intended to change all that. "Make no small plans," Hale liked to say. An accomplished astrophysicist, he was even more effective at scientific entrepreneurship. In 1904, Hale persuaded Andrew Carnegie to fund the Mount Wilson Observatory. His entrepreneurial vision increasingly extended beyond astrophysics to turning the National Academy, of which he was foreign secretary, into a vital agency in the affairs of national science.

Hale endorsed increasing the limit on annual elections to 15, and he called for the Academy to cooperate with local and national societies, a venture that would mitigate the exclusionist objection. He also urged that the Academy enlarge its influence by dispensing money for research, particularly to promising young men, publishing a proceedings, and acquiring a building, a permanent meeting home with lectures and exhibits open to the public.

All this would of course take money. To that end, American science in general and the Academy in particular needed to promote greater public appreciation and financial support of research, especially from industry and industrialists. However, both his failed attempts at fundraising and his study of science in Europe had taught Hale a critical lesson: "to accomplish great results," academies had to "enjoy the active cooperation of the leaders of the state." Hale held, in short, that the Academy's major twin purposes of advancing American science and advising the government were mutually dependent and had to be symbiotically joined.

Hale's opportunity came with World War I (WWI). Events in May 1915 made dramatically clear that more than any other conflict in history, this was a war of science and technology. That month, the Germans initiated chemical warfare by unleashing chlorine gas from hundreds of cylinders on the front at Ypres, in Belgium. Also that month, a German U-boat sank the *Lusitania*.

Both American scientists and the administration of Woodrow Wilson were appalled by the use of poison gas, and neither proposed a program of even defensive research in chemical warfare. However, American shipping was now clearly vulnerable to the depredations of German submarines, whether the nation was in the war or not. Shortly after the sinking of the *Lusitania*, Secretary of the Navy Josephus Daniels established a Naval Consulting Board headed by Thomas Edison to use "the natural inventive genius of Americans to meet the new conditions of warfare...." The Board's membership was drawn overwhelmingly from the country's major engineering organizations and included only two scientists, one a physicist and the other a mathematician, both as representatives of the American Mathematical Society. Early in October, at the Board's first meeting, the physicist demanded to know why Edison had omitted the American Physical Society.

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Edison's chief engineer explained: "Because it was his desire to have this Board composed of *practical* men who are accustomed to *doing* things, and not *talking* about it." A few minutes later, the physicist returned to his theme. Why hadn't the National Academy been represented on the Board?

"Possibly," the inventor Peter Cooper Hewitt speculated, provoking considerable laughter, "because they have not been sufficiently active to impress their existence upon Mr. Edison's mind."

George Ellery Hale, discontented by the omission of the Academy from the Board, wondered: Could not the Academy's reputation be raised to the point where it might "penetrate to the sanctum of the Secretary of the Navy?"

Hale shared the members' traditional wariness of thrusting the Academy on the government, but surely in a national emergency they could offer its services to the administration without appearing like mere political supplicants. They did just that, and in June 1916, following a meeting with President Wilson and a formal presidential request for assistance, the Academy created the National Research Council (NRC). The NRC's objective: to encourage both pure and applied research for the ultimate end of "the national security and welfare." Its strategy was to promote "cooperation" among all of the research institutions of the country. Its planned composition was leading scientists and engineers from universities, industry, and the government, including the military. Many scientific societies, research foundations, and universities quickly pledged the NRC their cooperation. So did a number of industrial leaders, especially from the emerging high-tech corporate world.

When in April 1917, the United States entered the European conflict, Hale declared that "War should mean research...and unless we get it started some other agency will do so." However, the NRC had little money of its own, and as a creature of the Academy, it was a resolutely private organization with no authority in government. It had to operate by argument and persuasion, making use of its members' connections in industry and government.

The key persuader was Robert A. Millikan, a likeable and energetic physicist and a future Nobel Laureate for the work he had done in 1909–1910 on measuring the charge on the electron and showing that every electron was identical. Then at the University of Chicago, Millikan was a consultant and a supplier of trained physicists to Western Electric and AT&T (one of his students, Frank B. Jewett, later rose to the top of the company). The company valued him highly for his expertise in figuring out the intricacies of the vacuum tubes it was developing with the aim of amplifying telephone signals so that they would reach from one side of the Continent to the other. He effectively straddled the worlds of academia and high-tech industry, and he was effective at working with officers in the military's technical bureaus.

Because the NRC had neither governmental authority nor significant funds, its officers accomplished the mobilization of science by enlisting in the military or going to work as civilians in federal laboratories, some of which were taken over by the military. Millikan himself became a colonel in the US Army. Led by Millikan, the NRC joined with other army and navy officers to inaugurate research and production for high-quality optical glass, drawing heavily on the substantial expertise of scientists at the Geophysical Laboratory of the Carnegie Institution, and to develop intelligence tests for the assessment and placement of the Army's 1.7 million recruits. Under the auspices of the NRC, the Bureau of Mines launched a program of research in chemical weapons—the distinction between offensive and defensive chemical warfare disappeared once American soldiers were committed to fight in France—and by May, the Bureau had farmed out problems to 21 university laboratories. All of the while, Millikan and John J. Carty of AT&T wrestled with approaches to the detection of submarines, with a considerable sense of urgency. The detection of submarines, Millikan declared, was only a "problem of physics pure and simple."

Soon the NRC became the sole agency in Washington that straddled every scientific constituency. Industrialists, working together with the people like Millikan in numerous agencies and committees, learned that academics could be hardheaded administrators and could treat technical matters with a practicality worth of an Edison. By Hale's report, the close contact of the NRC with federal and industrial officials was winning "many new friends for pure science." In March 1918, Hale moved to make the Council and its governmental connections permanent by obtaining an executive order for the purpose from President Woodrow Wilson.

Hale himself wrote the draft of the order. It provided, among other things, that the NRC continue to foster cooperative efforts in research in the government as well as elsewhere. That raised a red flag with Wilson, who doubted his "right to give any outside body" the power to coordinate the scientific work of the government. Wilson modified the order to ensure that the NRC, being a private organization, would not have any authority over federal scientific agencies and programs. Issued on May 11, 1918, the order asked the Academy to perpetuate the National Research Council. It also explicitly provided for future US Presidents to appoint to it federal representatives nominated by the Academy, which assured the Council the continuing participation of the leaders of the state, without their interference. Hale, who was principally concerned with what could be done for science outside the federal establishment, elatedly declared "We now have precisely the connection with the government that we need," and he intended to make good use of it to promote American science.

The connection with the state did not include ambitions for public funding of NAS/NRC activities. Hale and his allies feared that would open the door to distasteful supervision or perhaps tyranny. He would "not be disappointed if we have to rely on private funds for a long period in the future."

Between the World Wars

The Academy solidified its connections with industry in 1919 by finally creating a section for men who had contributed "to the science or art of engineering." Now, with its admirable war record and its extensive connections through the NRC to the multiple sectors of basic science and engineering, the Academy obtained private funds in abundance. The Carnegie Corporation provided operating money for several years, and then it granted the NAS/NRC $5 million, about a third for what became the Academy's building on Constitution Avenue and the rest for the operations of the NAS/NRC.

The NRC rapidly developed into an intellectually expansive operating arm of the Academy, doing much that, with its limited membership and disciplinary diversity, the Academy was ill equipped to do. The NRC established 13 interdisciplinary divisions, among them divisions of Biology and Agriculture, of Engineering, and of Anthropology and Psychology. The divisions in turn spawned multiple committees. Among those with high impact were the committees on Research in Sex and Reproduction, whose activities led to the Kinsey Reports; on Industrial Lighting, which unexpectedly yielded the striking result of the Hawthorne Effect; and on Highway Research, which helped shape the design of the nation's rapidly expanding roads. Other committees spoke to some of the day's other salient science-related issues, dealing with drug addiction, medicine and physics, and nutrition.

The new and handsome funding also equipped the Academy to play a far more significant role in the development of basic science, starting with the publication of its *Proceedings*. The Rockefeller Foundation established a program of postdoctoral fellowships that was administered by the

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NAS/NRC and that would prove to have a huge impact on raising the quality of American science between the wars and beyond. All of the while, the NRC created a set of committees to consider to major problems in various scientific disciplines and call attention to them by publishing bulletins—for example, John Van Vleck's *Quantum Principles and Line Spectra*.

Although President Calvin Coolidge addressed the Academy at the building's dedication in 1924, the NAS/NRC received hardly any requests for scientific advice from the government. In 1931, a committee appointed to look into the issue noted that the Academy had "not been taken seriously the by the Government" and attributed the problem in part to the rule that it "speak only when spoken to."

Amid the emergency of the Great Depression, however, the Academy deciding once again to be proactive, obtained an executive order from President Franklin Roosevelt and establishing a Scientific Advisory Board for 2 years beginning in 1933 that would operate under the auspices of the NAS/NRC. Chaired by the physicist Karl T. Compton, the president of the Massachusetts Institute of Technology (MIT), it was to report on how science and technology could contribute to the amelioration of the economy and the operations of federal science. In December 1934, the Board proposed a major program: a federal appropriation for research of $75 million for 5 years, justified on the grounds that new knowledge would lead to new industries, new jobs, and a boost to recovery.

The proposal was virtually dead on arrival. For one thing, the Board was undercut by internecine warfare between Compton and the President of the Academy, William Wallace Campbell, a former head of the University of California. He objected to the very existence of the Board because, while operating in the Academy, its membership had been appointed by President Roosevelt. He complained repeatedly to members of the administration about President Roosevelt's violation of the Academy's apolitical autonomy. Paying Campbell a visit to try to work things out, Compton found him adamant, and in his recollection of the meeting, he "blew up," writing that the Academy and Campbell could "be damned if they were going to insist on such trivialities and legalities in preference to grasping the opportunity to do a great public service."

However, also, the proposed appropriation for research failed because the Board declined to accept normal democratic oversight and accountability, insisting instead on autonomy in the allocation of the research money. The administration refused to appropriate what one official termed "a large 'free fund'" for projects that were not socially purposeful. Indeed, the economic payoff from the federal investment would come in the vaguely distant future, and people needed relief in the here and now. The Board's program reminded one key administration staffer of trickle-down economics, an approach to recovery that boiled down to Herbert Hoover's point of view.

Nothing came directly from the Board's efforts, but the experience gave several of its members—notably Compton and Jewett, the head of Bell Labs who would become president of the Academy in 1939—a basic education in federal science policy-making that would shape their approach to the mobilization of science in the coming war.

They key mobilizer was of course Compton's former MIT colleague, Vannevar Bush, a veteran of a branch of the NRC's submarine detection effort in WWI that operated at New London, Connecticut, under the control of the Navy. He had chafed at such control because it prevented the civilian scientists and engineers from pursuing research in military devices that made sense to them but not necessarily to the naval officers. He believed that if science for defense was to be organized effectively, it had to be done independently of the military, under the wing of the President of the United States, and not through the Academy.

Bush had no trouble enlisting to this view either Compton, given his experience with William Wallace Campbell in the episode of the Science Advisory Board, or Jewett, who had met Bush in the submarine warfare laboratory at New London, Connecticut, during WWI and, having been a member of the Academy since 1918, was more steeped in its traditions. Jewett thought that an agency other than the NAS had to mobilize and direct defense research. The NAS was like "a doctor waiting for clients." It could not act as "an aggressive salesman" hawking its expertise for military purposes. To do so would turn it into "just another agency of government" and destroy its most valuable asset, "the authority of distinction without power."

With the support of Compton, Jewett, and James B. Conant, the chemist, president of Harvard, and also a scientific veteran of World War I, Bush prevailed on President Roosevelt in June 1940 to establish the National Defense Research Committee (NDRC), and then, in June 1941, the Office of Scientific Research and Development (OSRD), which included the NDRC. The work of OSRD helped mightily to achieve the stunning and decisive technical successes of World War II, from microwave radar through the atomic bomb.

Both the NDRC and OSRD were of course agencies of government, but both were authorized to obtain assistance in their work from the NAS/NRC. And obtain it they did, as did other federal agencies. During the war, the NAS/NRC provided multiple advisory and administrative services to the scientific mobilization on issues ranging from surveying the availability of scientific personnel in the nation's colleges and universities to assessing the feasibility of going ahead with a project to produce an atomic bomb. The Academy signed 34 war-related contracts with 10 federal agencies for such purposes. Its building here on Constitution Avenue was occupied by several divisions of the NDRC, by the whole of the OSRD Committee on Medical Research, and by some 20 other groups with war contracts from the NDRC. Every nook and cranny of the building was laced with partitioned offices.

The Postwar Era

After the war, the leadership and the membership of the NAS/NRC understood that there was no going back, no returning to the era when the Academy's functions comprised, as one scientist put it, "electing members and writing obituaries." Nor should there be, many members realized, given the essential importance of science to national security and the importance of avoiding the divorce of academic and industrial science and engineering from the military that had followed World War I. However, under what arrangements was the Academy, still an insistently private organization, to serve national security in the postwar world?

At first, the NAS overreached, much as Hale had done in framing the executive order for the continuation of the NRC in 1918. The overreach took the form of a move to establish in the NAS/NRC a Research Board for National Security (RBNS) that would conduct defense research for the armed services. Harold Smith, director of the Budget Bureau, had warned President Roosevelt in March 1945 that the Academy was "very jealous of its non-governmental status, and under its control the Research Board for National Security would [work on weapons of war but inappropriately] not be responsible to...the Commander-in-Chief."

The proposal for the RBNS failed, but the Academy was of no mind to withdraw from engagement with the government simply because it could not have that engagement on its own terms. On the contrary, Jewett, in recognition of the wartime experience and now the looming Cold War, abandoned the policy that the NAS could act only when called on, and his successors also embraced proactivism.

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In the postwar years, the NAS/NRC provided an increasing number of advisory and administrative services to the government, with significant boosts occurring during the Korean War and in the several years after Sputnik, in 1957. The efforts ranged from inner space—oceanography—to the sciences of outer space; from studies on the long-term health effects of the atomic bombings of Hiroshima and Nagasaki to inquiries on food and nutrition. Throughout the period, the Academy also continued to promote science—for example, administering the National Science Foundation (NSF) fellowship program and sponsoring the landmark conference at Shelter Island in 1947, where, among other things, Willis Lamb reported his unexpected spectral shift and Feynman first publicly discussed his remarkable diagrams. Between 1945 and 1960, the NAS/NRC budget more than quintupled to $14,725,000.

The Academy's entanglement with the government at times strained its principles, notably in the postwar decade when considerations of loyalty and security threatened the civil liberties of scientists. For example, in 1947, the physicist Edward U. Condon, the head of the National Bureau of Standards, was pilloried for his left-leaning politics by the House Un-American Activities Committee (HUAC). Frank Jewett deplored the HUAC's actions, and so did many other members of the Academy. A number wanted the Academy to take a public stand, but the Council, including Vannevar Bush and President A. N. Richards, was reluctant to do so. "The most unfortunate outcome would be to jeopardize our relations with Government" Richards said. In the end, the Academy confined itself publicly to a tepid expression of "grave concern" over HUAC's treatment of Condon. A few years later, however, in January 1955, the Academy courageously issued a report that ended security restrictions on most federally funded fellowships, declaring that no one should be denied a fellowship for unclassified research solely on grounds of an allegation of disloyalty.

In all, during the postwar years, the Academy richly realized the twin purposes that Alexander Bache and Louis Agassiz had established for it: advancing science and serving the government. If George Ellery Hale had recognized that the two were symbiotically linked, his postwar successors did so even more. In 1961, the Academy fortified the link by creating its Committee on Science and Public Policy (COSPUP). COSPUP took the initiative, without waiting for requests from the government, to report on important and promising directions for future scientific research and in the applications of science to critical public problems. Its reports spanned topics from basic research and national goals to a 10-year program for ground-based astronomy.

President John F. Kennedy perhaps helped inspire the creation of COSPUP when, addressing the Academy in April 1961, he spoke of the "many new frontiers" of science and of his conviction that never before, even in WWII, had there "been a time...when the relationship between science and government must be more intimate." By then, after a century of experience in the American democracy, the Academy had, by and large, figured out how it could insulate itself from political control while serving a government that insisted on oversight and accountability. The relationship had at times been uneasy, but when President Kennedy returned to speak at the Academy's Centennial in 1963, he found it worthy of admiration, and so can we.

National Security and International Relations

The members of the Academy elected the institution's first foreign associates in 1864, just a year after the Academy's creation. Since then, the institution's involvement in international activities has steadily increased. An 1866 study looked at the navigability of Nicaragua's San Juan River as part of a possible canal across Central America. The Academy's Committee on Weights and Measures encouraged the United States to become the first signatory, in 1875, to an 18-nation treaty on international standardization. In 1907, astronomer George Ellery Hale became the Academy's delegate to the conference of the International Association of Academies, and in 1908, he became chairman of the Academy's Committee on International Cooperation in Research.

The Academy's international activities expanded greatly after Hale presided over the formation of the National Research Council in 1916. Four speakers at the colloquium examined aspects of this involvement. Peter Westwick, assistant professor of history at the University of Southern California, examined how the Academy has sought to reconcile its service to government with its commitments to internationalism. Richard Garwin, fellow emeritus at IBM's Thomas J. Watson Research Center, described the Academy's efforts to maintain bilateral communications with Russia, China, and other countries even during the worst days of the Cold War. Matthew Meselson, Thomas Dudley Cabot Professor of the Natural Sciences at Harvard University, recounted several highlights of the Academy's work on chemical and biological arms control. Michael Clegg, Donald Bren Professor of Biological Sciences, Ecology, and Evolutionary Biology at the University of California, Irvine, detailed some of the activities of the Academy's Foreign Secretary as examples of how the institution's influence has come to extend well beyond the borders of the United States.

Reconciling National Security with Scientific Internationalism

Peter Westwick, *University of Southern California*

The Academy was created in the context of war—specifically, the Civil War—and providing technical advice to the US military was one of its original justifications. Subsequent history seems to have reinforced this military connection, from the creation of the NRC during World War I to the Academy's many contributions in World War II.

The Academy's founders had an additional motivation, which was to promote American science. For the first several decades, this function looked mostly inward to domestic processes. However, through developments like the NRC fellows program in the 1920s, the Academy increasingly sought to connect American science to the international scientific community.

That meant reconciling the aim of serving national security with pursuing the ideals of scientific internationalism. At times these goals have aligned, but at other times they have been in tension. For example, during World War I and its aftermath, the Academy acted to exclude German scientists from international scientific organizations, whereas after World War II, the Academy backed the integration of German science to aid in the reconstruction of Western Europe.

Science in Warfare

A development paralleling the growth of the Academy over the last 150 years—and one that the Academy itself helped bring about—has been the increasing presence of science in warfare. It is tempting to connect the Academy's growth to this military role, to say that World War II and the Cold War helped drive the growth of the Academy, as they helped drive the growth of much of American science in this period. Indeed, in the mid-1950s, half of the academy's funding came from the Department of Defense (DOD) and the Atomic Energy Commission (AEC).

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However, ironically, science's increasing military importance seems instead to have diminished the Academy's influence, so that much of the Academy's growth over the last 50 years seems to have occurred outside its direct military role. The reason is the proliferation of science advisory committees, like the AEC's General Advisory Committee, the Defense Science Board, and the JASONs, along with think tanks like the RAND Corporation and the MITRE Corporation, which have competed with the Academy for an advisory role. The Academy's voice was notably absent from several key issues, including the debate over the hydrogen bomb in 1949, conducted largely within the AEC's General Advisory Committee; the intercontinental ballistic missile debate in the mid-1950s under Air Force groups; and discussions of missile defense in the 1960s, where the JASONs were prominent.

Some defense work did continue through the early Cold War—for instance, on undersea warfare and civil defense. Food and nutrition, transportation, education, and other topics were related at the time to national security. However, direct advice to the Defense Department declined, and by 1970, only 3% of Academy work involved classified defense topics.

Even that amount was enough to attract attention, because in addition to competition from advisory committees, defense work was challenged from within. In the Vietnam era, Academy members Richard Lewontin and Bruce Wallace resigned to protest the Academy's military studies, with Lewontin at one point asking, "Is the Academy just another RAND Corporation?" This episode roiled the academy for several years around 1970, and I understand it made for some lively annual meetings. Part of the issue, as Dick Garwin will describe, was the relation between the Academy and NRC reports. Academy President Philip Handler perceived a deeper question of whether the Academy should exercise "moral as well as technical leadership." Handler generally answered that question in the affirmative, but he defended military studies—not only because the Academy was obliged to do them by its Congressional charter, but also because it might serve as a moderating influence. In the end, the Academy elected to continue classified studies, with the membership to receive unclassified summaries of defense projects, and within a couple years, the controversy subsided.

By the 1980s, a review of the classification policy found that few Academy members knew about it, let alone adhered to it. One might speculate that the Vietnam episode left its main mark not on the Academy but rather on the military.

In major strategic debates in the later Cold War, such as the Strategic Defense Initiative (SDI) in the 1980s, the Academy was again notably absent. Perhaps Lewontin and the other Vietnam protestors achieved their goal not by forcing the Academy to turn away from the military but by persuading the military that the Academy was an unwilling partner, so the military looked elsewhere for advice.

Arms Control

The Academy played a larger role in arms control. In the age of the nuclear arms race, the Academy provided advice not so much on developing new weapons but rather on controlling them. Amid the Vietnam debate, Handler began pushing for a "Commission for Peace" to balance military projects. This role took some time to emerge. For one, the Academy struggled to find sponsors willing to pay for such work. For another, the Council worried that technical issues in this arena were inseparable from political ones. The Academy had had some interaction with the arms control group Pugwash going back to the 1950s. However, when there were proposals to increase these interactions in the 1970s, George Kistiakowsky judged that the Academy and Pugwash were "immiscible."

Handler's efforts eventually led to the Committee on National Security and Arms Control (CISAC). Through CISAC, the Academy played an important role for the SDI, although behind the scenes instead of in public. Another important distinction is that CISAC, in the case of SDI and other arms control issues in the 1980s, was advising the State Department and not the Pentagon. In the 1980s, the State Department's lack of scientific expertise not only hampered it in negotiations with the Soviets but also in internal debates within the administration.

The 9/11 Attacks

The Academy responded to the 9/11 attacks with a study entitled *Making the Nation Safer*. All three academies wrote to President Bush volunteering their services in the national emergency. When the President did not jump at their offer, the Academies took it upon themselves to do the study, funded out of the Academies' endowment, and the subsequent report proved to be influential. However, this strikes me as interesting. Here we have a major crisis in national security—just the situation the Academy was created for—and the government did not ask it for advice.

This was not necessarily a new development. Consider World War I and the maneuvering by Hale and others to create the NRC, or World War II, when the Academy had to help jumpstart the atomic bomb project, or even the Academy's creation during the Civil War, which was instigated by the maneuvering of scientists. The pattern may be universal; in the French Revolutionary wars, Lavoisier and other French chemists struggled to persuade political leaders to support their work on new weapons.

Perhaps this pattern is for the best. The Academy in peacetime has kept some distance from the military, not becoming captive or being perceived as captive to military interests. That gives it a valuable independent perspective, but it might mean that each time there is a national emergency, the Academy has to reestablish its role in national security. By comparison, the Soviet and Chinese academies were under the state and more tightly integrated with national security interests, which meant more direct influence but also less independence.

Science Exchanges

The Academy has promoted international science through many means, including international conferences and unions, the International Geophysical Year, and interaction with science academies abroad.

One important avenue has been science exchanges. The Academy entered into an exchange agreement with the Soviets in 1955, after the death of Stalin, with the goal of building cultural and political ties. Like the NRC fellows in the 1920s who helped rebuild European science after World War I, exchanges encouraged a sense of international cooperation amid the Cold War. Trip reports from American scientists visiting the Soviet Union, even in the wake of the Cuban Missile Crisis, convey an impression of genuine warmth between American and Soviet scientists and the hope that scientific relations would build bridges between the two countries. However, the Soviet scientists doubted the situation would improve, owing to the meddling of Soviet party apparatchiks. There also were bureaucratic hassles on the American side, such as visa issues. However, perhaps more important were the deeper ideological divisions, which persisted despite shared scientific values. It was the Cold War, after all, when Doug Cornell, the Academy's executive officer, spoke of a war to the death between ideologies, and Academy President Detlev Bronk warned of "the predatory advance of the godless ideology of communism."

East-west exchanges sputtered along into the détente of the 1970s, at which point the Academy undertook several reviews of the experience. These reviews concluded that the exchanges were worthwhile in strengthening

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American international science and in reducing political tensions. However, two decades of experience had clearly led to lowered expectations. A more pessimistic Academy member called the exchanges "a disaster area." Few Americans wanted to spend much time in the Soviet Union, except perhaps for social scientists. In the other direction, the Soviets sent over second-rate scientists, or worse, party hacks who spent their time in the states on shopping trips instead of science.

Meanwhile, the Federal Bureau of Investigation (FBI) feared that many Soviet exchange students were in fact spies. A COSPUP panel asked if that meant that scientists got debriefed on their return; if so, well, the United States did that too. That did not mean that scientists were engaged in active espionage.

The role of intelligence in these exchanges is understandably hard to assess, but it again suggests some of the potential tensions between strengthening national security and promoting international science. There were other examples from the early Cold War of scientists providing scientific or industrial intelligence—for instance, as attachés in oversees embassies. One of the explicit justifications for science exchanges was to help keep the United States abreast of Soviet developments in science and technology, and the Academy reviews judged them successful in this respect.

Human Rights

Perhaps the thorniest issue for exchanges was human rights. In the 1970s, human rights emerged as a central issue for US-Soviet relations, expressed especially in the Helsinki Accords of 1975. At the time, the dissident movement in the Soviet Union included many scientists, most notably Andrei Sakharov. The Academy faced a dilemma: how to pressure the Soviets on Sakharov and other refuseniks, yet maintain science exchanges.

As it had earlier under McCarthyism, the Academy balanced pragmatic accommodation against moral principles. Science offered a way to improve political relations, but cooperation might imply acceptance of human rights abuses. Some Academy members sought to keep science and politics separate, but others insisted that, as one put it, "scientists must take strong moral and social stands as well as intellectual ones."

In 1980, Handler gave a widely noticed talk in Hamburg that included a strong statement on human rights, and the Academy suspended exchanges. Many members applauded Handler's stand, but others, including Harvey Brooks, thought it was a mistake, possibly cutting off interaction and hence influence, especially just when CISAC was seeking to engage the Soviets on arms control. And Soviet scientists indeed warned that cutting off relations only strengthened the hand of Soviet hardliners. However, when the Academy resumed exchanges a few years later, it was roundly criticized for sending scientists to Moscow while Sakharov was wasting away in a hunger strike.

The Academy expressed this tension in competing committees. The Committee on USSR and Eastern Europe pushed science exchanges, whereas its counterpart, the Committee on Human Rights, pushed for stronger moral stands. The Committee on Human Rights had been created in 1977 to address the issue of human rights in the Soviet Union, but it expanded its purview to Chile, Somalia, and several other countries, including China.

The example of China posed some familiar problems. The Academy had earlier formed a separate committee on cooperation with China in May 1966, which was eventually named the Committee on Scholarly Communication with the People's Republic of China. This was not great timing, coming just before the onset of the Cultural Revolution, which targeted science in particular as a bourgeois influence. However, the Academy demonstrated great prescience and patience. It kept the committee alive so that it was ready and waiting when the revolution consumed itself and relations between the United States and China improved in the 1970s. Nixon's agreement with China in 1972 explicitly called for science exchanges as a way to build bridges. The Academy's nongovernmental status made it a more acceptable mechanism to the Chinese, and the Academy supported a flurry of exchanges with China in the 1970s, helping pave the way for formal diplomatic relations.

Even before formal relations resumed in 1979, enthusiasm was eroding in the Academy. China sent many more delegations than it hosted, and it tended to send engineers and receive social scientists. Handler and others worried about the asymmetry and pressed for parity. Initial idealism gave away to a more pragmatic calculation of national interests.

A decade later, in 1989, the protest at Tiananmen Square again raised the issue of human rights. As the Tiananmen tragedy became clear, the Academy debated whether to maintain exchanges as a way to relieve oppression or to suspend them to protest the massacre. The Academy in the end suspended exchanges, but it continued to debate whether this was helping or hurting Chinese scientists. Within a year, it elected to gradually resume the exchanges.

The China program had a longer-term impact. As Frank Press noted in 1978, through these exchanges, the American academic community was "training the next generation of Chinese leaders." Press perceived that this training included values as well as specific techniques and theories. Also, although Press did not say it, scientific values could perhaps provide a liberalizing influence.

The Tiananmen Square protest seemed to realize this possibility, as physicist Fang Lizhi and other scientists played leading roles in the democracy movement. Similarly, in the Soviet Union, scientists were among the leading dissidents. In one view, this was no accident, because the international ideals of science stress open communication, rational debate, and other democratic ideals. More recently, after the 9/11 attacks, an NRC panel urged science exchanges with Muslim countries that had thriving scientific communities to foster mutual communication and understanding, and, perhaps, liberal values.

Balancing National Interests and International Ideals

The Academy's national security role has diminished over the last several decades, in part because the Academy succeeded beyond its wildest expectations in helping the military realize the value of scientific expertise. A corollary has been to realize the goal of enhancing the American science community, including international projects, which can extend the goals of promoting national security and promoting American science. A political scientist might call this a shift from hard power to soft power, and the Academy indeed must be worried that its international programs are not just seen as another assertion of American hegemony or as a way to Americanize international science. For example, American science initiatives in Western Europe in the early Cold War were sometimes viewed this way, even when they were consensual.

However, international science programs were not just about power calculations. They also were driven by the ideals of science. That has often required difficult balancing between national interests and international ideals, but it seems to have been worth the effort.

Maintaining International Dialogue

Richard Garwin, *IBM Fellow Emeritus*

The Committee on International Security and Arms Control was created in 1981 with the support of NAS presidents Philip Handler

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and then Frank Press to meet semiannually with Soviet counterparts. These bilateral meetings with Soviet scientists, engineers, and military officers, all of whom were used by the government of the Soviet Union, led to greatly increased understanding of the attitudes of the two sides and to options for reducing the peril of nuclear war.

As was the case with President Eisenhower on his election in 1952, Mikhail Gorbachev, when he took office in 1985, sought independent expertise in matters of military technology. Feeling he could not rely on the military, Gorbachev created an informal national security kitchen cabinet of Evgeny Velikhov, Roald Sagdeev, Evgeny Primakov, and Georgi Arbatov, all of whom had been involved with the CISAC process for several years by that time.

Frank von Hippel has recently published an account of his interactions with Gorbachev's informal advisors. Particularly notable is the early discussion of directed energy weapons in space, before President Regan's thunderclap of a speech in March 1983 initiating the program his White House liked to call "Star Wars," which went formally by the name Strategic Defense Initiative. This was a shock, coming a week after a March 16, 1983, meeting at the Academy in which the focus was the technology of beam weapons in space, but with no hint of the presidential announcement. The Soviet side published an analysis based, as was common then, on US publications, concluding that space-based antimissile systems are too technically complex, expensive, and easily defeated by countermeasures to be worthwhile. This was portrayed by many in the United States as insincere and disingenuous propaganda. In my opinion, it was anything but. Indeed, the conclusions stand the test of time well.

In the CISAC Russian-Academy Bilateral, we discussed substantively and frankly the prospects of nuclear war command and control systems, monitoring and verification of disarmament, the Comprehensive Nuclear-Test-Ban Treaty, and the like. CISAC became virtually the only bridge of communication on issues of arms control between the USSR and the United States. The Russia dialogue today continues to address these and other issues, which remain both irritants in US-Russian relations and potential opportunities for cooperation.

Interactions with Other Countries

In 1988, the CISAC meetings were extended to bilateral sessions with the Chinese Academy of Engineering Physics, which is the nuclear weapon organization in China. In particular, the activity in China was organized by the Institute for Applied Physics and Computational Mathematics (IAPCM), the theoretical design branch of the Chinese nuclear weapon effort. Sometime IAPCM Director Hu Side chaired and still chairs the Chinese counterpart group. Meetings began under CISAC chair Pief Panofsky and continued under John Holdren and now Raymond Jeanloz, through good times and bad times. Important achievements of these interactions, which take place without publicity and with no open reports, include a deep understanding of the attitudes on the two sides and, in particular, the Chinese government's signing the Comprehensive Nuclear-Test-Ban Treaty.

One major achievement between the two groups was the Chinese-English Nuclear Security Glossary, which is available on the web. The effort led to the Chinese government proposing to do a similar glossary effort among the five permanent members of the Security Council, and the Chinese chair of the Academy glossary effort led the Chinese delegation to the P5 meeting. Similarly, the Chinese group and CISAC convened the first meeting between Chinese and US nuclear laboratory and forensics experts. After these two meetings were convened in this way, the governments were able to establish regular meetings of these experts without us. This is a model that the CISAC hopes to replicate in its other dialogues.

The bilateral meetings have been extended to discussions with India, although not to the depth or to the involvement of the counterpart government, as with the Soviet Union, Russia, and China. This interaction has been very active of late and recently convened an unprecedented joint India-US workshop on science and technology for nuclear materials security, including scientists from the weapons establishments of both countries.

The Academy also has been active in counterterrorism and organized to provide a response immediately after the Al-Qaeda attacks of 2001. The report was, in my judgment, a remarkably rapid and reasonable analysis of the situation. Also along the lines of countering terrorism, the CISAC held a workshop in Goa, India, in January 2004. Indian colleagues at the Institute for Advanced Studies indicated a desire to reprise this topic following the terrorist attacks in Mumbai, so another joint workshop will be held in February, 10 years after the first one.

The Value of Information

The NRC and CISAC are limited by the availability of funds for travel, lodging of volunteers, and staff salaries. Also, the preparation of classified reports is much impeded by mandatory classification review, and government elements often take advantage of that to censor the substance of reports and delay publication. However, the Academy study process has become more efficient with the ubiquitous employment of computers for report generation. I also believe that the impact of the reports is much enhanced by the National Academy Press's policy, decades in the making, of providing all NAS/NRC reports free as PDF files for download. Very often an advisory report of some kind within the government or outside cannot be produced at the moment in which it would be more effective. However, it helps to educate the people in government and people who will be in government in the future: if not senators and representatives, at least their future staff. Providing reports in archival and searchable form is terribly important.

The Academy and Chemical and Biological Weapons

Matthew Meselson, *Harvard University*

In 1963, I was working at the Arms Control and Disarmament Agency and was assigned to look into biological and chemical weapons. I went to Fort Detrick, Maryland, and when I asked why we were developing these weapons, I was told by the man who was taking me around that it would save us money, because it would be cheaper than nuclear weapons. That lit up an incandescent bulb in my brain. I went back to the agency and discussed it with my officemate, Freeman Dyson. We agreed that cheapness was the worst possible justification for developing a weapon of mass destruction. Ever since then, I've been interested in biological and chemical weapons.

Early on, I took part in an academy panel chaired by George Kistiakowsky, who was also instrumental in creating the Report Review Committee. The Army had a lot of obsolete nerve agent weapons outside of the Denver airport at Rocky Mountain Arsenal, and there was great interest in getting rid of these. The Army had loaded various chemical munitions and agents in bulk tanks on railway cars and was going to ship them to Elizabethport, New Jersey, put them in liberty ships, and dump them in the ocean by scuttling the ships. However, governors of states along the way said they would not let the trains go through, so the Army turned to the Academy for advice on how to dispose of the weapons. This was, as far as I know,

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the first involvement of the Academy in chemical demilitarization, something that became an immense job after the entry into force of the Chemical Weapons Convention, which requires destruction of the entire stockpile.

At one of our meetings, Kistiakowsky asked whether the generators were still in the ships, and the Army representative said no, we have taken them out. However, at one of our meetings, George showed a movie. He had gone down into the hull of one of these ships, and there were the generators, still bolted tight. He explained that as a ship sinks, it does not go down flat; it tilts. George was a master metallurgist, among many other things, and he knew the generators would rip off their bolts and crash into the cargo. The cargo consisted of 21,000 cluster bombs, each containing 76 bomblets, including 2,000 tons of sarin. George was concerned that there might be a sympathetic explosion of the entire load of chemical bombs if the generators rammed into the cargo as the ship tilted, especially considering that the acoustic coupling constant in water is much greater than in air.

The image brought up was of a lethal nerve gas cloud coming westward from about 100 mi east of Atlantic City and covering a very large land area. Finally, after a dead silence that seemed to last a long time, a panel member from the Navy said, "That just shows what can happen if you let the Army play around with ships." The Academy panel recommended that the cluster bombs not be dumped at sea, and in the end, they were all destroyed at Rocky Mountain without, so far as I know, a single lost-time chemical accident.

With the advent of the sea dumping law, the Law of the Sea Treaty, and finally the Chemical Weapons Convention, the United States embarked on a massive effort to destroy all of its large stockpile of chemical weapons. There was mustard that had been made during World War II. There were sarin weapons that had been made at Rocky Mountain Arsenal. There was another nerve agent called VX, which is more persistent than sarin. There were also the facilities for making these things. All had to be destroyed under the Chemical Weapons Convention, which entered into force in 1997 and is now about 90% complete and estimated to cost a total of some $40 billion.

Several different technologies for chemical weapons destruction were extensively evaluated and compared in a still-continuing succession of Academy reports. These included alkali hydrolysis of agent, incineration (with the argument that this gets rid of everything), and finally explosive decomposition, all of which were used or are still being used, and several other technologies considered but not adopted.

Biological Weapons

In 1983, Joshua Lederberg established a biological weapons subgroup of the CISAC, and it met with the Soviets numerous times. This was very different from the nuclear discussions of the CISAC because of a profound asymmetry. In the nuclear area, there was access to the key Soviet experts and officials who were making policy about nuclear weapons. There was nothing like that with respect to biological weapons on the Russian side. As a result, it was a completely asymmetric discussion. Our objective was to make friends, begin to create a degree of transparency, and fortify the norm against the use of chemical and biological weapons, and it remains an ongoing effort today.

One of the key issues between the two delegations was the discussion of the anthrax outbreak at Sverdlovsk, USSR, in 1979. Here, I want to point out a way in which the Academy can have important indirect effects. During one of the CISAC biological weapons meetings, we hosted a Soviet delegation visiting Fort Detrick, and I got to know one of the Russian visitors. A few years later, Boris Yeltsin asked this man to study the Sverdlovsk anthrax outbreak. Learning of this, I sent him a telegram asking if I could come and help him and go to Sverdlovsk to study the outbreak. He replied that, yes, I could come to Sverdlovsk, but I would need to be invited by someone there. The Academy had an exchange agreement with the Soviet Union, and in 1979, an American physicist from the University of Illinois was living there for 3 weeks during the outbreak. I called him in Illinois to ask if he knew anybody in Sverdlovsk who could invite me. He replied that his physics colleague from Sverdlovsk was visiting Illinois and was sitting next to him at that very moment. That got me an invitation to bring a small team to Sverdlovsk, now restored to its old name, Ekaterinburg, to investigate in 1992 and again in 1993.

As you may know, we were able to show that this epidemic resulted not from the eating of contaminated meat, as the Soviet government had claimed, but from an airborne release. We found and published in *Science* that the cases occurred in a narrow zone extending 50 km from a military biological facility in the city into the countryside, and there was 1 day and 1 day only just before the first cases when the wind was in exactly that direction all day long.

What this story demonstrates is that everyone who serves on Academy committees does not go into cold storage between meetings. We are all active in other venues. Also, Academy reports are not a one-way street. Panels educate the members of the panels, so that when Academy members and other members of those panels go out into the wider world, their understanding is more fact based than it would otherwise be. In this way, Academy activities help to create a body of knowledgeable opinion within the body politic of the country.

The Academy's Office of Foreign Secretary

Michael Clegg, *University of California at Irvine*

The National Academy of Sciences was formed in the image of European academies, and in the 18th and 19th centuries, European academies had a tradition of electing foreign scientists to membership and encouraging scientific exchange and correspondence. Not surprisingly, the initial constitution and bylaws of the Academy included an Office of Foreign Secretary with two stipulated duties. One was to manage the election of foreign scholars to the Academy. The other was to manage the correspondence of the Academy with other academies around the world.

The initial class of Academy members included 50 individuals, and in the next year, the Academy elected an initial class of 10 foreign associates, including such distinguished scientists as the Irish physicist W. D. Hamilton and the British chemist Michael Faraday. Today about 420 distinguished foreign scholars are members of the Academy.

For most of its history, the foreign associates of the Academy have been drawn from European countries. However, over the last 15 or 20 years, the Academy has sought to broaden its rank of foreign associates to recognize the development of scientific excellence and competence globally, and the foreign associates now include many more scholars from Asia, Africa, and Latin America than before.

Foreign associates play an important role, because they are not only distinguished scholars but also, in many cases, people who have had high posts in their own government and have access to the highest levels of government. They constitute an important informal resource for the work of the NRC throughout the world.

Inter-Academy Cooperation

The second part of the job—correspondence with other academies—has become very

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complex. Many different programs involve cooperation with other academies around the world. A few examples will demonstrate the kind of work that has evolved and has become particularly active during the last 25 years.

One of the first efforts to do a joint policy study with another academy was initiated under Frank Press, in which the Academy worked with the Mexican Academy of Sciences on the water supply of Mexico City. The joint project initiated a continuing close relationship between the NAS and the Mexican Academy of Sciences. Another important project on water futures in the Jordan Valley involved the Israeli and Palestinian Academies of Science and the Jordanian Higher Council of Science. This joint project represented an ambitious effort to use science as a bridge-building exercise between societies in conflict. In some regards, the project was very successful, but the political situation has continued to decline in that region of the world, so follow-up efforts have been difficult to achieve.

An ongoing effort aimed at using science in a bridge-building exercise is a series of more than 25 workshops held since 2000 between the NAS and the Science Academy of Iran. This exercise receives tacit support from the Iranian Government and active support from the US State Department. These workshops have dealt with a wide array of different topics, including seismic hazards, scientific ethics, and wildlife management issues. The goal is to keep channels of communication open with the Iranian scientific community.

It is difficult to achieve funding for most of these exercises, and there is much more that the NAS could do in using science as a link between nations. Therefore, to be as efficient as possible, the Academy has sought to work with many partners simultaneously. This history of engaging many partners goes back to the end of the 19th century, when the Academy, together with a number of European academies, banded together to create an organization known as the International Association of Academies. The primary purpose of that organization was dealing with the communication and commerce of science across linguistic and national boundaries. It addressed such things as scientific measures, agreement on scientific nomenclature, and other important issues for the commerce of science. After about 30 years, this organization evolved into the International Council of Scientific Unions in 1931, an organization later renamed the International Council for Science. Today, it is the scientific counterpart to United Nations Educational, Scientific and Cultural Organization and other United Nations (UN) agencies and seeks to articulate and help organize ambitious global science projects.

In the early 1990s, the Academy and about eight other academies, including the Royal Society, the Indian Academy of Sciences, and the Mexican Academy of Sciences, banded together to write a white paper on the issue of human population growth. The resulting document was quite important at the time, and it made what was then a novel argument: that the key to human population control was the empowerment of women. A couple of years later, in an effort led by the Royal Society of London, an ad hoc group of science academies developed a white paper on the issue of transgenic crops in agriculture.

On the basis of these experiences, the academies decided jointly to create a global network of science academies, and this was done under the leadership of F. Sherwood Rowland, my predecessor as Foreign Secretary. Following this, Bruce Alberts, during his presidency of the Academy, helped create a second organization linked to the global network of science academies whose purpose was to do NRC-type studies addressing global issues. This organization, called the Inter-Academy Council, is headquartered in The Netherlands and has done a number of important policy studies on major issues at a global level, including reports on the importance of scientific capacity in national development, the issue of food security in sub-Saharan Africa, the global importance of women in science, the 21st-century energy transition, and a worldwide framework for scientific ethics.

Regional Cooperation

During his presidency, Bruce Alberts also helped conceive and find financial support from the Bill and Melinda Gates Foundation for a 10-year project to work with academies in sub-Saharan Africa. The goal of this program, called the African Science Academy Development Initiative, was to help the academies of sub-Saharan Africa develop the skills to provide science policy advice to their own governments. That program is now in its 10th year and has been remarkably successful.

A final example of regional cooperation among academies is an organization known as the Inter-American Network of Academies of Sciences. This organization includes all of the academies of the American Hemisphere from Chile and Argentina to Canada, and it works on a number of important issues, including improving the quality of K-12 science education, advancing opportunities for women in science, and water and energy issues. This network of academics has brought the NAS into much closer contact with our counterparts in the Americas than in the past.

The International Geophysical Year and Beyond: From the Earth to the Solar System

The Academy's work on space exploration has been an important complement to its leadership of international science. Beginning with the planning of the 1957–1958 International Geophysical Year (IGY), the Academy helped coordinate national and international efforts to study the earth from its interior to the edges of the atmosphere. So successful was the IGY that it was extended for the International Geophysical Cooperation year of 1959.

The creation of the Space Science Board by the Academy in 1958 "to survey the scientific problems, opportunities, and implications of man's advance into space" created an institution that would cement the Academy's role in the nation's rapidly growing space program. At the colloquium, Sylvia Fries Kraemer, former National Aeronautics and Space Administration (NASA) chief historian and director of policy development, described the creation of the Space Science Board and some of its successes in advising government. Allan Needell, curator in the Space History Division of the National Air and Space Museum, then focused on Lloyd Berkner, one of the architects of the IGY and the first chair of the Space Science Board.

From IGY to the Space Science Board

Sylvia Fries Kraemer, *Former NASA Chief Historian and Director of Policy Development*

Complex human events like the beginning of space exploration are endlessly fascinating to historians, because they typically consist of many moving parts. Individuals and institutions that enable those moving parts to function together effectively are among the most important and most underappreciated actors in the history of human enterprise. In the exploration of space, the National Academy of Sciences played this essential

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role, coordinating and mediating a number of essential moving parts.

Drivers of the US Space Program

The first and quite literally foremost factor in the development of the US space program was the sun. The periodic flares and electromagnetic storms known as the solar maximum were due to recur in 1958, creating a rare opportunity for the growth of global and atmospheric science.

Second was the preparatory work done during the late 1940s on rocketry at the California Institute of Technology and elsewhere. At White Sands, New Mexico, the Army and Navy Ordnance Bureaus and the Office of Naval Research launched rockets into the upper atmosphere that consisted initially of reassembled German V2 rockets with scientific instruments instead of explosives in their warheads.

Third were the scientists and technicians from universities, as well as the military services, who designed the scientific rocket payloads and reviewed the results of each flight. They provided the core of the unofficial upper atmosphere rocket research panel formed in 1946 and would become key figures in the scientific exploration of space in the next three decades.

Fourth were the institutional capabilities of those among the nation's universities that had rapidly grown their physical science faculties and research plans under the stimulus of World War II and early Cold War federal grants and contracts.

Fifth was the national security environment. Launching an artificial satellite into orbit required the capabilities of guided missiles. Until the creation of NASA in 1958, the only institution in the United States both able and authorized to launch guided missiles was the military.

The National Academy of Sciences, and especially its US National Committee for the International Geophysical Year, coordinated and mediated among these moving parts. As it did so, it laid the template for the future conduct of US civilian space exploration. This template had three salient features.

First, socializing risk and privatizing gains have been the national policy for the promotion of research and development in this country ever since the first federal research and development (R&D) contract was negotiated with Eli Whitney in 1798. However, in the post-World War II era of big science and technology, socializing risk and privatizing gains became a far more complicated task than merely issuing a contract from an office in the War Department. The Academy mastered that complexity.

The second salient feature is pluralism. Although the Federal Government has financed much of this nation's space research and development, it has been scientists trained in private or state operated universities and used by them, as well as research-intensive companies in the aerospace and defense industries, that have done the bulk of the work. The Academy attracted the first generation of space scientists to a truly cosmopolitan undertaking far beyond the laboratory.

The third salient feature has been international participation in US space exploration. The Academy represented the United States on COSPAR, the international committee on space research. More importantly, beginning in 1957 when the National Academy of Sciences masterminded participation in the IGY, US space science missions have combined launches, payloads, and experiments from around the world.

The National Academy of Sciences brought to the dawn of space exploration a vital legacy of experience with a broad range of research in which the distinction between pure and applied science was an academic distraction at best. In accumulating this experience, the Academy had formed working relationships among a diverse range of individuals and institutions and had developed a solid appreciation of the needs of its federal client agencies. The Academy was the US representative to the International Council of Scientific Unions, which asked it to develop and direct the scientific and technological program for US participation in the IGY. In turn the Academy would coordinate funding with the National Science Foundation, which would have to come from Congressional appropriations. Thus, on February 10, 1953, Academy President Detlev Bronk formed the US National Committee for the IGY and appointed UCLA Professor of Physics Joseph Kaplan as Chairman, with Lloyd Berkner, an ionospheric physicist at the Carnegie Institution, taking over as chairman after Kaplan resigned the following year.

Developing a Civilian Space Program

Elected in 1952, Dwight Eisenhower was the first president since Ulysses Grant to have had personal experience of the indiscriminate and unforgiving carnage of modern warfare. Millions of lives could be spared if military confrontation with the Soviet Union could be avoided, and untold amounts of money could be saved for domestic needs if a costly buildup of the military-industrial complex could be minimized. This would require ongoing and accurate assessments of the Soviet Union's actual fighting capabilities.

If the international principle of freedom of space for objects in orbit could be established, all spacefaring nations could make foreign and military policy decisions on the basis of relatively accurate knowledge of each other's' military capabilities. What better object to establish that principal than a scientific satellite orbiting over the earth's airspace below as part of a peaceful international scientific venture?

As inclined as President Eisenhower was to approve the earth satellite program, the route to his desk was guarded by several agencies that needed to vouch for the program's feasibility. Only the Defense Department could provide and operate the launch vehicles and communications networks. Because foreign governments were involved, the State Department also would have to give its support. For comparable reasons, approvals were needed from the National Security Council, the Central Intelligence Agency, and the Bureau of the Budget.

Nevertheless, by all accounts, Bronk, with the help of Berkner and National Science Foundation Director Alan Waterman, gave persuasive briefing after briefing and participated in meeting after meeting and discussion after discussion. In the end, they managed to funnel all of the necessary recommendations into the Oval Office.

Thus, it was at the opening of the International Geophysical Year on July 1, 1957, when President Eisenhower said toward the end of his remarks, "I should like to congratulate all who have helped to make our program possible, and particularly the National Academy of Sciences. Through its National Committee for the International Geophysical Year, the Academy has worked tirelessly to plan and coordinate the program in cooperation with other nations."

The division of responsibilities among the Academy's US National Committee, the Defense Department, and the National Science Foundation was sorted out over dinner at the Cosmos Club in July 1956. Briefly, the Academy would be responsible for all scientific aspects of the program. The DOD would determine the workability of instruments proposed for the satellites; develop, procure, and launch the vehicles; deliver the satellites into orbit; confirm their orbits; and provide logistical and technical support as well as radio tracking. Any public information required clearance from the DOD as well as the Academy. The National Science Foundation was the fiscal agent.

First and most fundamentally, the nation's space program would be a civilian, and thus peaceful, undertaking. Second, the scientific content of the program would be the responsibility of the scientific community, whether

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used in the country's universities or, as was the case after 1958, used in a civilian space agency. Although now taken for granted, it was never written in the stars that it should be so.

Bronk undoubtedly had misgivings about the NASA bill that would be introduced into and approved by the House of Representatives in 1958. The bill lacked any provision, comparable to the National Science Board that advised the National Science Foundation, for a group of outside scientists to oversee the NASA space science program.

On June 4, Bronk invited NSF's Waterman, Berkner, Herbert York, who was chief scientist of the Advanced Research Projects Agency (which managed all civil and military space activity between 1957 and the opening of NASA in October 1958), and Hugh Dryden, who was director of NASA's predecessor agency, the National Advisory Committee for Aeronautics, to meet with him at the Academy to design what would become the new Space Science Board.

The principal mission of the board would be to ensure that the Academy could and would represent the views of American scientists in US space program planning and also to promote international cooperation in space research. Unfortunately, from the board's perspective, President Eisenhower declined to name Hugh Dryden, a Johns Hopkins PhD in physics who was a familiar presence at the Academy, to the NASA post. Instead, Eisenhower gave the nod to T. Keith Glennan, a Yale-trained electrical engineer and a proven executive in corporate government and academic organizations. Glennan's organization of NASA headquarters placed space science at a third tier management level. As for its Space Science Program, NASA's official policy was that the agency, and it alone, would formulate a national program of space research, although using recommendations from the Space Science Board, educational research institutions, industry, other contractors, and internally generated ideas.

The Space Sciences Board, in its diminished role, was to become NASA's chief critic. The board complained to the President's Science Advisory Committee that NASA was doing science in-house and thus failing to support university-based scientific research. It complained that NASA was neglecting basic science, that government-conducted science was not as good as science done in university and industrial laboratories, and that NASA's contractor payload engineers were failing to involve the payload scientists sufficiently in the work.

However, all was not critical. Board Chair Berkner would break the mold among many space scientists and publically distance himself from their opposition to the space program. Instead, he supported human exploration as the emotive fuel necessary to sustain a successful national space program.

As often happens in Washington, much of the energy behind this controversy was dissipated by a change of administrations. After the Democratic Party recaptured the White House in November 1960, John F. Kennedy announced what became the Apollo manned lunar landing program. At the urging of Lyndon Johnson and others, he named James E. Webb as NASA Administrator. Meanwhile, Berkner wrestled his colleagues on the Space Science Board into adopting a policy statement supporting NASA's human exploration of the moon and planets.

Webb was one of this country's sharpest and most talented public servants, a veteran of the hill, the Department of State, and the Bureau of the Budget. His appointment also produced a sea of change in NASA relations with space scientists. Webb understood from his own Washington experience that if NASA was going to be able to achieve its mission, every congressional district, every research industry, and the entire aerospace industry would have to have a material interest in the agency's success. This meant that NASA's procurements, contracts, and research grants needed to be genuinely accessible to anyone across the country. This also meant, in Webb's reorganization of NASA headquarters, the creation of an Office of Space Sciences on par with an Office of Manned Space Flight. The Space Science Board soon became an officially acknowledged direct advisory group to the administrator.

For its part, the Academy and Space Science Board eventually accepted the fact of human exploration and the political realities that NASA had to deal with in serving many constituencies while doing justice to its founding mission. The role of the Space Science Board became to take the long view, a perspective difficult for agency managers to maintain during the constant political and budgetary changes afflicting government programs.

Role of the Space Science Board

The Space Science Board has advised NASA through its periodic summer studies, through its decadal studies of future space research needs, and through investigations responding to federal agency or congressional requests. This can be illustrated by the influence it and the Academy exercised over three key decisions.

The first was the board's successful promulgation in 1963 of a code to avoid the contamination of the moon, planets, and other celestial bodies, a code that was adopted by the International Council of Scientific Unions as well as NASA and the DOD. The board has continued to promote methods for preventing contamination of celestial objects by space probes.

Another was a successful effort to persuade NASA, once the initial Apollo lunar landings were completed, to train scientists to serve as astronauts and develop a genuine science astronaut program. From 1971 through December 1972, NASA flew four primarily scientific Apollo missions, 14–17, to the moon, with full-fledged scientists trained as astronauts on their crews. Scientist-astronauts soon became regular members of human spaceflight crews.

A third example is the Board's 2005 assessment, at NASA's request, of the comparative benefits and risks of a robotic mission versus a manned shuttle mission to service the Hubble Space Telescope one last time in its then anticipated life. The board argued persuasively that a shuttle servicing mission was well worth the same risks that were being taken to service the International Space Station. The fifth and last servicing mission for the orbiting telescope was flown in May of 2009, and the Hubble Space Telescope continues to generate extraordinary images of the heavens to this day.

In the mid-1980s, the Space Science Board changed its name to the Space Studies Board to recognize that its portfolio had expanded from the academic space science disciplines that emerge from the IGY to preparing studies and testimonies not only for the Congress and NASA but for the National Oceanic and Atmospheric Administration, created in 1970, and for the US Geological Survey.

A Template for Space Science

In contrast to the situation in the Soviet Union, the Academy had no power to command the human and material resources necessary to launch a space program. It had to work within the political and fiscal realities of our system of constitutional government.

In the course of coordinating the necessary moving parts within those realities, it shaped the template for the following decades of space exploration, not only by the United States but to a large extent by our international partners in space. The Space Science Board has provided guidance in the short run and has become a vital source of vision in the long run.

Lloyd Berkner and International Science Policy

Allan Needell, *National Air and Space Museum*

Lloyd Berkner was among the most influential figures to come out of World War II.

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Following his service during the war in the Navy Bureau of Aeronautics as the leader of the bureau's radar and communications electronics procurement effort, and as primary liaison with the scientists working at the MIT Radiation Laboratory on radar, he built for himself an impressive reputation as an organizer, administrator, and government advisor during the Truman Administration. In 1947, he served as the first postwar manager of the Joint Research and Development Board, whose job was to evaluate defense-related research and development activities to prevent duplication and to maintain close relations between the nation's defense and scientific communities. He also served as an official advisor to the Department of State.

Never actually earning an advanced degree himself, it was with great satisfaction and professional pride that in 1948 he accepted formal nomination to the Academy. Especially welcome was the prospect that in addition to recognizing both his own scientific achievements and his organizing activities, the Academy would provide him with further opportunities to organize scientists as a force for addressing national problems.

Berkner soon was asked to take part in Academy business. In July 1948, Isaiah Bowman, President of Johns Hopkins University, agreed to a State Department request to chair a special Academy conference on research in Antarctica. Aware that Berkner had participated in a 1928 expedition to Antarctica, Bowman asked the Academy, and specifically Berkner, to contribute a report on ionospheric research in that region, Berkner's research specialty. Berkner agreed and proposed a relatively ambitious Antarctic research program to study atmospheric electricity and magnetism.

This program was not unlike that undertaken during the IGY. In his report, Berkner emphasized that such research could best be accomplished by the combined efforts of scientists from many nations. Berkner's recommendations made a great deal of scientific sense, but it is no coincidence that they also provided the State Department with the sort of diplomatic ammunition it had been seeking.

Contemporary documents reveal that it was the military that had sparked the sudden State Department concern with Antarctica. The Navy feared that the Soviet Union might try to use bases established there to gain control over shipping lanes. Unwilling to allow the Soviets to pursue sovereignty claims in Antarctica, military planners pressed the State Department to increase diplomatic efforts to forestall such action.

It is hardly remarkable that Berkner would champion international scientific cooperation in Antarctica, having worked throughout the 1950s cultivating just such cooperation in ionospheric research. What is remarkable is how well and with how little apparent strain the revival of such efforts could be made to mesh with the newer, and increasingly secret, peacetime national security agendas then emerging.

Berkner was confident in his belief, one that was widely shared among scientists of that era, that the interests of increasing knowledge, promoting intellectual freedom, and maintaining American national security neatly coincided. Berkner was uniquely prepared for the sensitive role of middle man between science and the emerging Cold War national security state.

The Berkner Report

Berkner's role at the now legendary April 1950 dinner party at the Silver Spring, Maryland, home of James Van Allen, in which planning for a third International Polar Year, which eventually becoming the IGY, was begun, is perhaps the story best known about Berkner among scientists. It is no coincidence that the dinner party occurred during the same month in which Berkner completed another major project involving the Academy, the so-called Berkner Report, *Science and Foreign Relations*. During the early part of 1949, with Secretary of State Dean Acheson's concurrence, then Under-Secretary of State James Webb established an internal review of State Department responsibilities in the field of science. Berkner was tapped to manage the report writing effort. Writing over Webb's signature to A. N. Richards, the President of the Academy, Berkner invited the Academy to assist in whatever manner it considered appropriate. He suggested the appointment of an advisory committee within the National Research Council to review the analysis and recommendations once they were prepared by internal government working groups, and he asked the NRC to produce its own paper to reflect the views of universities, research organizations, and other nongovernmental entities concerned with the problem. By calling on the Academy and the NRC, Berkner added prestige and influence to the State Department report and helped ensure that American scientists would feel that they had at least some say in the recommendations that were made.

To bolster that impression, in early April, before the Van Allen dinner, Berkner attended the business session of the Academy's annual meeting to formally report on the results of the State Department's study and the contributions made by the Academy. Berkner was determined to emphasize the stake he believed his Academy audience had, not only in the report's endorsement of the importance of scientific research, but also in the more controversial aspects of the report. International science policy, he stated, should be devoted to "the maintenance of that measure of security of the free peoples of the world required for the continuance of their intellectual, material, and political freedom."

Left unsaid was that science was then perceived as an increasingly important target for national intelligence gathering. In that regard, Berkner had prepared a classified appendix to the 1950 report outlining ways in which American scientists could be of direct assistance to the intelligence community. One of the major recommendations was to increase participation in international activities, along with the creation of both overt and covert intelligence operations to exploit them.

In his work with the State Department, Berkner was walking a delicate line, attempting to serve as a broker between the national security bureaucracy and the professional community of scientists. Although to the Academy audience he emphasized the service to science the State Department could provide, in the confines of the State Department meeting rooms and in classified documents, he emphasized the government's hidden agenda.

The revelation of Berkner's secret agenda should not be taken to indicate a lack of sympathy for the goals, needs, and ideals of his fellow scientists. Subsequent actions suggest that he remained sincerely interested in furthering those goals and in pursuing the proposals made in the unclassified report, not only for nationalistic reasons but also because of an abiding personal interest in international science. That the IGY coincided with the separate needs and goals of several agencies of the Federal Government did not bother Berkner to any extent. To the contrary, the opportunity to work simultaneously for science and for the nation had a tremendous appeal to him as a planner, administrator, and scientist. To him, as to most of the leaders of the scientific establishment that emerged after World War II, the goals of science, the goals of the international community of free people, and the interests of America neatly coincided.

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Climate Change

Climate change is a problem well suited to the Academy's multidisciplinary structure. It involves energy production and consumption, land and water use, agriculture, international cooperation, and scientific communication. The scientific disciplines involved in studying climate change range from atmospheric chemistry, geophysics, and ecology to economics, anthropology, and sociology. Although coordination of all these topics within the Academy has sometimes been challenging, the institution has produced a steady stream of reports since the 1970s that have alerted the public to the problem and have recommended ways to ameliorate it.

At the colloquium, Spencer Weart, director emeritus of the Center for the History of Physics at the American Institute of Physics, reviewed the Academy's four decades of work on the issue of climate change. The Academy's president, Ralph Cicerone, explained why the response to the threat posed by ozone-destroying chemicals in the atmosphere has been so much more forceful than the response to the threat posed by greenhouse warming. Peter Gleick, cofounder and leader of the Pacific Institute for Studies in Development, Environment, and Security, cited several areas in which further work by the Academy could advance the science and build momentum for social change. Naomi Oreskes, professor of the history of science at Harvard University, pointed to the need for much greater involvement of social scientists in the Academy's work on climate change.

A History of the Academy's Involvement in Climate Change

Spencer Weart, *American Institute of Physics*

The National Academy of Sciences has been extensively involved with the issue of climate change, but the first collective statement on global warming by a group of scientists, issued in 1963, was not from the Academy. The impetus was David Keeling's demonstration that the level of carbon dioxide in the atmosphere was rising dramatically year after year. That prompted the private Conservation Foundation to convene a meeting, and that meeting set the pattern for many later ones.

Several experts on the role of carbon dioxide in climate, along with a handful of experts in forestry, agriculture, and so forth, produced a consensus report warning that if fossil fuel burning continued, the earth will be changed, more than likely for the worse. They could scarcely say what would happen in the next century. The only thing they felt confident about was that there would be a rise in sea level, bringing immense flooding to low-lying areas. Their primary recommendation was that more research was needed and more money should be spent on research. Meanwhile, they called on the Academy to create a committee to look into the issue.

The next step was taken by the President's Science Advisory Committee, which had formed a pollution panel to address issues such as smog. It included, however, a subpanel to discuss the effects of carbon dioxide on climate. The subpanel reported that there could be marked changes in climate and predicted, with remarkable foresight in 1965, that such changes might be apparent by the year 2000. Without attempting to say anything specific about impacts, the subpanel remarked that the changes could be deleterious for humans.

Meanwhile, another form of climate change had become a national issue—namely deliberate modification of climate through artificial rain making or other interventions. In 1966, the Academy answered a government request to report on climate modification. The report of the panel included, as a minor side issue, the question of inadvertent climate modification from greenhouse gas emissions. The panel warned against what it called dire predictions of drastic climate changes. It remarked that the geological record shows swings of temperature, and although some of these natural climatic changes had locally catastrophic effects, they did not stop the steady evolution of civilization.

However, the panel did believe that the buildup of carbon dioxide should be watched closely. Its primary conclusion was, again, that more money should be spent on research.

Among the few scientists who paid attention to climate theories, concern grew. A landmark study on human impacts on the global environment was conducted at MIT in 1970 and concluded, among other things, that greenhouse warming might bring widespread droughts and changes to the sea level. Meanwhile, the international community launched the Global Atmospheric Research Program (GARP), partly in response to greenhouse warming concerns but mainly to improve weather prediction and other near-term issues. To manage American participation in GARP, the Academy set up a US committee that included many top scientists.

The Academy's Involvement Grows

In 1975, the Academy's GARP committee published an influential report. More alarming than previous Academy statements, it declared that society simply cannot afford to be unprepared for either a natural or a manmade climatic catastrophe. The committee agreed that there was a significant likelihood of a major deterioration of global climate in the years ahead but could not say what sort of a deterioration. Global warming was just one possibility.

In 1960, the Academy had established a geophysics review board, which dealt with international research in the field and coordinated the Academy's activities. In the early 1970s, the board took up the idea of a decadal survey of geophysics. This survey grew to 24 reports in all, given the fragmented nature of the geophysical community.

One of the reports was on energy and climate. This panel of experts announced, in 1977, that average temperatures might climb as much as 6 °C by the middle of the 21st century. Unlike previous reports, the panel was specific about the potential impacts. On the positive side, the Arctic Ocean might eventually be open to shipping. On the negative side, marine ecosystems might be seriously disrupted. Stresses on the polar ice caps might lead to a surge of ice into the sea, bringing a rise in sea level of about 4 m within 300 years. In agriculture, there could be benefits, but also terrible disasters like the recent African droughts. The panel concluded that world society could probably adjust, given sufficient time and a sufficient degree of international cooperation. However, over shorter times, the effects might be adverse and perhaps even catastrophic.

The Academy's experts were by no means prepared to recommend actual changes in the nation's energy policies. They only suggested that the world might eventually need to reduce the use of fossil fuels. As a page 1 headline in the *New York Times* summed it up, "Scientists fear heavy use of coal may bring adverse shift in climate."

The Academy's call for more and better organized research did not fall on deaf ears. The meteorological community and its friends in the federal bureaucracy were determined to push for a consolidation of climate research. In 1977, the Academy created the Climate Research Board with, unusually, a full-time chair, Robert White. The board coordinated the Academy's climate work and provided a channel for advice to the government. It also took the lead in promoting a consolidated federal research program, and in 1978, the Congress passed the National Climate Act and established the National Climate Program Office.

The next significant report came from the JASONs. In a 1979 study, they looked into the chances for a climate change of any kind, whether global warming or otherwise. They

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concluded that the world's food supply could shrink and sea levels could rise. In either case, there could be a displacement of populations, creating a national security problem.

The president's science advisor, geophysicist Frank Press, now asked the Academy for a report. In particular, he wanted a second opinion on what the JASONs had identified as the most crucial issue—namely, the validity of computer models of climate. A summer study convened for a week in Woods Hole in July 1979 under veteran computer modeler Jule Charney.

Charney's group found that the different computer models were all in the same ballpark for the temperature in an atmosphere containing twice as much carbon dioxide. To make its conclusion more concrete, the Charney panel announced, with rather high confidence, a specific range of numbers: 3 °C, give or take 50%. This has stood up remarkably well over the years. The latest report of the Intergovernmental Panel on Climate Change (IPCC) cites 3 °C as the most probable value, give or take a degree or two.

The panel also remarked that absorption of heat by the oceans would delay a noticeable rise of heat in the atmosphere by decades. A wait-and-see policy, the panel declared, may mean waiting until it is too late.

From Energy to Climate

This quiet conclusion was not entirely remote from politics. In the wake of the oil supply crisis of the 1970s, the nation was considering a massive program to produce synthetic liquid fuels from coal. Some scientists warned that this would lead to a massive outpouring of carbon dioxide and used greenhouse warming as an argument against the synfuels program.

One incident provides a small example of the work that the Academy does outside the formal structure of reports and out of public view. On July 18, 1979, even as the Charney panel was gathering at Woods Hole, the Academy's president, Philip Handler, got a call from Senator Abraham Ribicoff. The Senator was cosponsoring a bill on synfuels, and he wanted to know the implications of greenhouse warming. Handler went to the National Research Council's Climate Research Board, and the very next day, it produced a statement on carbon dioxide and energy policy. The statement confirmed that global warming could be a problem. The statement told Senator Ribicoff that the massive expenditures required to create a national synthetic fuels capability should not commit the nation to large-scale dependence on coal for the indefinite future. This is the first time that an Academy group issued a specific policy recommendation, ambiguous although it may be, related to global warming.

Eventually, Congress passed the 1980 Energy Security Act, which set up a synfuels program and provided for renewable energy sources. It also appropriated funds for a more substantial Academy study of greenhouse warming and its policy implications.

In 1983, the Academy issued the product of this effort, a 496-page report entitled *Changing Climate*. The scientists agreed that they were deeply concerned. They pointed to consequences that could barely be imagined—for example, if global warming released methane, a potent greenhouse gas, from seabed sediments. These cautions, however, were only passing remarks within a summary that was, on balance, reassuring.

The committee chair, William Nierenberg, and some of the economists involved in the policy advice sections of the report were skeptical of warnings of future disaster. They saw environmental regulation as a danger to free markets, and they believed that America's technological prowess and adaptability would surmount any problems. Projecting a mere degree or two of temperature change in the foreseeable future, Nierenberg's summary of the report said that climate change is far from novel. Large numbers of people live in all climatic zones and move easily between them. At worst, people who found themselves in the wrong place could move, as people had often done in the past. Heading off any threat of government policy-making, the panel's chief recommendation was that the only thing to do at present was spend more money on research.

Americans might have ignored the report, but 3 days earlier, the Environmental Protection Agency (EPA) had released its own report about the greenhouse effect. The science was mostly the same, but the tone was more anxious. Substantial increases in global warming may occur sooner than thought likely, with possibly catastrophic consequences. The report insisted that work on new energy policies should get underway without delay. The result was a public debate. As *Time* magazine put it, at the very least, the inhabitants of the planet must begin looking more seriously into how they might live in a new, hotter world.

Starting in 1983, various organizations came together to develop an international geosphere-biosphere program, and other international activities were under way. Most significant was a conference that gathered scientists from 29 nations at Villach, Austria, in 1985. The scientists found that global warming would be faster and more serious than Nierenberg's group had predicted. Pointing out that the rate of future warming could be profoundly affected by governmental policies, the Villach report called on governments to consider positive actions. Indeed, the conference's report gave direct policy advice, calling on governments to consider a global convention to prevent too much global warming.

In 1988, a world conference convened about 300 scientists and others in Toronto. For the first time, a group of prestigious scientists called on the world's governments to set strict specific targets for reducing greenhouse gas emissions—namely, to reduce carbon dioxide emissions by 20% from 1988 levels by the year 2005 as an initial global goal. It helped that this conference was held during the summer of 1988 when exceptional heat and drought in the United States caused much public worry about climate change.

Congress, concerned by the public uproar, called on the Academy to conduct a new study. The charge was to establish the scientific consensus on the rate and magnitude of climate change, estimate the projected impacts, and evaluate policy options for mitigating and responding to such changes. The Academies, including the National Academy of Engineering and the Institute of Medicine, undertook a massive effort. The scientists involved ranged from so-called alarmists like Stephen Schneider to so-called deniers like Richard Lindzen. The panel finally produced a 944-page report, *Policy Implications of Greenhouse Warming*, which was published in 1992, although the public had seen the main results in April 1991.

A common first impression was captured by the headline in the *New York Times*: "Panel says nation has ability to adapt to global warming." The Associated Press story found the panel optimistic about the ability of American industry and farming to adapt to the climate change and quoted from the report: "Human adaptability is shown by people working in both Riyadh and Barrow. Recent American migration has, on average, been toward warmth."

In an unusual step, the Academy published a dissent by one of the panel members, the policy expert Jessica Matthews. Disruptions would be worse than the panel predicted, she insisted, and she remarked tartly, "The fact that one can move with ease from Vermont to Miami has nothing to say about the consequences of Vermont acquiring Miami's climate."

Looking closer at the report, the panel was far from advocating the wait-and-see position that had dominated the report chaired by Nierenberg. It recommended undertaking mitigation with international cooperation. By the panel's reckoning, insurance against global warming was cheap. The panel considered

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restricting emissions directly through taxes and regulations. It judged that, in general, incentive-type measures are preferable. The government should impose national energy-efficient building codes, strengthen support of mass transit, use incentives to increase automobile gasoline mileage, and so forth. Overall, the panel felt that emissions could be cut between 10% and 40% below the 1990 level at low cost and at some net savings.

As *Time* magazine put it, both sides could find some support for their positions in the study. Its findings and recommendations could prod the go-slow faction in George Bush's White House and brush aside claims, many emanating from the White House, that reducing greenhouse emissions would be wildly expensive and a blow to economic growth. Overall, the report provided a comprehensive and sophisticated menu of options for both mitigation and adaptation. If a good fraction of the panel's recommendations had been implemented, the nation would be in a much stronger environmental and moral position today. Unfortunately, the report got scant attention from the White House or from Congress.

The Academy and the IPCC

That was the last comprehensive Academy global warming study for a long time because work had risen to the international level. Starting in 1988, the IPCC began a process leading to massive reports that far exceeded, in international political clout, anything that the Academy could have attempted.

That did not leave the Academy without a role. There remained many kinds of specialized studies relating to global warming that it was in a good position to undertake. Meanwhile, a minority of scientists were speaking out against the IPCC's gradually coalescing consensus. The most widely noted technical criticism came in brief reports issued between 1989 and 1992 by the conservative George C. Marshall Institute. The anonymously authored pamphlets came with the endorsement of Frederick Seitz, a former head of the Academy.

Most prominent of the skeptics' claims was that if warming had, in fact, been observed in the 20th century, it could all be explained by an increase in solar activity. In 1990, the National Research Council's Board on Global Change decided on its own initiative to look into the question. In 1994, it issued a report that unequivocally rejected these skeptical claims.

The skeptics now turned to measurements by satellites that monitored the earth. According to an analysis by one group, there has been no rise of temperature of middle levels of the atmosphere but, instead, a slight cooling. It was as if one set of observations could disprove that the planet was warming.

In an attempt to settle the controversy, the National Research Council again appointed a panel to conduct a full-scale review. The panel concluded that something was wrong. Perhaps some temporary influence was keeping the midlevels of the atmosphere from showing the warming that was bound to happen. The panel's hunch was confirmed in 2004 when meticulous analysis of the satellite data showed that, in fact, the earlier analysis had been incorrect and that there had been warming in the middle levels of the atmosphere.

One final example involved the "hockey stick" controversy. Michael Mann and colleagues produced a curve showing a sudden recent rise of temperature with a slope like a hockey stick. Deniers of climate change came up with many objections to the curve's validity, and, in 2005, Representative Joe Barton, chair of the House Energy and Commerce Committee, launched an investigation that promised to give the deniers a platform. The new president of the Academy, Ralph Cicerone, wrote to Barton to oppose a Congressional investigation. Better, said Cicerone, to ask the Academy to undertake a study.

A defender of science, Representative Sherwood Boehlert, asked the Academy to review all of the evidence of surface temperature measurements. Again, a panel was duly formed, and again it found that the hockey stick was basically valid, which has been borne out by many subsequent studies.

On a larger scale, the George W. Bush administration wanted to reject the conclusions that the IPCC was reaching. As Time.com reported, skeptics in the administration suspected that a left-wing conspiracy had sought to take control of energy policy by whipping up a panic based on science. They believed that asking questions would disprove the claims of those calling for action on global warming, so they went to the Academy with questions framed to give them the answers that they wanted. The Academy had less than a month to respond to the questions. Diverging from the usual slow process of soliciting funds from government agencies, the Academy supported the study out of its own resources. The result was exactly the opposite of what the White House wanted to hear. The committee reported that the IPCC's conclusions accurately reflect the current thinking of the scientific community on this issue.

In 2010, the National Research Council released the Academy's most comprehensive survey on the issue to date. With more forcefulness than ever, *America's Climate Choices* insisted that future climate change was a severe problem that required an immediate policy response. The Academy issued specific and urgent demands for legislation to address both mitigation of climate change and adaptation to the changes that are already inevitable. The report, however, had no effect on the legislation that was before Congress. In 2009, the House of Representatives had managed to pass a bill that would institute a cap and trade scheme. The Academy report was published in May 2010, and in July, the bill died in the Senate where the Republican minority exercised a veto through threats of filibuster.

A Report Card

What does this history of half a century of activity tell us about the Academy's choices and its influence? In the 1960s, the first important initiatives were taken by groups outside the Academy. From the 1970s on, Academy panels and committees repeatedly and correctly took the lead in stating that there was a possibility of harmful impacts, which would show up around the start of the 21st century and get worse thereafter.

As expected from panels of leaders in climate science, their judgments reflected the state of confidence in the community as a whole. The conclusions ranged from uncertain worries in the 1960s and early 1970s to precise warnings in the 1990s and thereafter. Beginning with the Charney report of 1979, the Academy's reports said it was virtually certain that global warming was on the way. This was in the face of denial from a minority of scientists. On several occasions, the Academy confronted deniers and refuted their claims with statements that history has shown to be correct.

In policy-related areas, the record is more spotty. Into the 1990s, Academy reports were ambiguous or even optimistic on the question of how severe the impacts of future global warming might be. Impacts research was then in its infancy, and this was a judgment call. It is worth noting that international conference reports tended to issue stronger warnings than the Academy's panels did. Until the 1990s, the Academy only called for more money and advised a wait-and-see policy. This, too, was backward compared with the calls for action issued by international conferences of climate scientists. However, in retrospect, if the Academy had issued earlier calls for policy, they likely would have been futile.

The calls for better organization and more money for research were partly successful, but only partly. There was never as much money as the gravity of the problem demanded.

The specific calls for policies to mitigate greenhouse emissions that the Academy issued from the 1990s all met with limited

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success. The press took note of the reports, and some recommended measures were enacted, such as restrictions on automobile gas mileage and support for renewable energy research.

However, the Academy's voice was only one in a cacophony of shouts. Indeed, all scientific bodies together were only one group among the bloggers and news media, the environmentalists and industry organizations, the politicians, and many others who had much to say about global warming.

Overall, the Academy devoted repeated and arduous efforts to global warming, but it was exerting its weight on an issue where much larger social and economic forces come to bear.

Ozone Destruction and Climate Change

Ralph Cicerone, *National Academy of Sciences*

The world's response to the threats posed to the ozone layer by chlorofluorocarbons has been very different from the response to climate change. In 1974, a theory came forward that chemicals in widespread use worldwide, chlorofluorocarbons (CFCs), could survive the upward journey into the ozone layer in the stratosphere, where they would be broken apart by mechanisms much more powerful than they encountered at the surface of the earth. There they could release chlorine atoms, which in turn could catalytically destroy about 100,000 ozone molecules before the catalyst had to be renewed.

Meanwhile, years after the discovery of the DNA molecule, it was determined from laboratory measurements that UV light can decompose human DNA, such as in skin. At the same time, epidemiological work had demonstrated connections between exposure to UV light and skin cancer, at least in light-skinned people, which generated enormous public interest.

Chlorofluorocarbons had started out to be ideal refrigerants, enabling air conditioning to go to places like Florida and Washington, DC. However, by 1974, the world was using most CFCs in spray cans of catnip, hairspray, underarm deodorant, and many other products, constituting a multibillion dollar industry in the United States.

An active group of science journalists, which does not exist much anymore, wrote about the story. Congressional hearings were immediately convened, and not many people were involved in the science, so a few of us got invited again and again to state and federal hearings in 1974 through 1978. We began to meet with staff people, who told us that the volume of mail that Congress received on the CFC-ozone problem exceeded anything that they had ever experienced before, except for the Vietnam war.

There were demands for regulation of these products. After all, if there was a threat to the entire global environment and to something that would involve human health and biological productivity, something should be done. However, Congress did not know what to do, so President Gerald Ford put together a federal taskforce.

The first job for the taskforce was to find out where in the federal government jurisdiction would be. However, only about 2% of the aerosol spray products being sold with CFCs as the propellant were under the jurisdiction of any federal agency, including the Food and Drug Administration, the Consumer Product Safety Commission, or the Environmental Protection Agency. At that point, the federal government turned to the Academy. There were many hearings and popular statements that Congress would not do anything until the Academy had analyzed the situation.

The Academy formed two groups: one a subgroup of the other, to look at the physics and chemistry of the atmosphere and, to a lesser extent, at biology. As usual, the project took longer than expected. It was scheduled to be released in the spring of 1976 and came out in the fall, but for a good reason. Some new chemistry had been proposed by Mario Molina and Sherwood Roland showing that the atmospheric chemistry might be more complicated than originally thought and that more intermediate chemicals could be involved.

Headline stories in the *New York Times* and *Washington Post,* on the same day, responded to the report. The writers of the report wrote skillfully and with a great deal of qualification. They said that a couple of more years of research could determine if regulations could be adopted and optimized. Federal regulations did follow within a couple of years on the production, sales, and use of these compounds. In addition, consumers had made up their minds, and sales of these products dropped.

In 1985, the ozone hole was discovered over Antarctica. It was totally unpredicted and could not be explained by the original chlorine vs. ozone theory. At that point, the public got very concerned. I remember giving a lecture in California in front of 500 or 600 people. The crowd turned angry at the end of my lecture. Why didn't you scientists see this coming? How could you have missed this continent-wide disappearance of the ozone layer?

The Montreal Protocol took effect in 1987, and it has been updated several times since that time. Substitute chemicals have been discovered and put into widespread use. It has been mostly a success story.

What is the difference with the climate situation?

In the case of CFCs, the public had already judged that aerosol spray products were not essential, and there were substitutes to these chemicals. In the case of carbon dioxide, the strong connection between human energy consumption, fossil fuels, and carbon dioxide levels is pervasive. It is hard to escape the need for transportation, heating, electricity, and lighting. In the case of the CFCs, there were only six producers in the world, and the public could blame the problem on them. In the case of fossil fuel use, it is hard to avoid seeing yourself in the mirror as one of the people causing carbon dioxide releases. Renewable sources of energy, although very appealing and necessary, are not yet available at the needed scale.

Climate is inherently more complex than understanding ozone in the stratosphere. For example, the biota are involved in climate change in a fairly direct way, whereas the biota are only affected by ozone loss.

The ozone situation was framed as a science issue, and the ozone hole turned out to be completely due to chlorofluorocarbons and a few bromine compounds. In the case of climate change, because of what is needed and how difficult and expensive changes might be, the issue has not been framed largely as a science issue. The people who are fighting about the realty of climate change focus mostly on policy and very little on science.

There are, of course, other dimensions, such as people in industries who are trying to undercut the science. Nevertheless, I am often asked how we could be so successful in protecting the ozone layer from further damage while failing to enact even the low-hanging fruit responses to climate change, such as strong commitments to better energy efficiency.

Next Steps for the Academy

Peter Gleick, *Pacific Institute for Studies in Development, Environment, and Security*

The Academy deserves enormous credit for tackling the climate change issue early and often, even in the midst of a difficult political

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climate. The Academy has many strengths in this context. It was established explicitly to do nonpartisan research, it is independent of government, and it has the ability to do interdisciplinary research, which is not as easy in universities or professional societies. Also, the committee structure of Academy panels permits expertise from a wide variety of areas to be brought to bear on problems.

Another strength of the Academies is the ability to reach out to the public with public communications. The climate issue is highly politicized and polarized issue, which means that more effort is needed on communications. Finally, because it is independent, the Academy cannot be shuttered like the Office of Technology Assessment was.

What does this mean for climate change? First, more science remains to be done on such issues as the role of radiative transfers, complex forcings, and the sensitivity of the atmosphere to greenhouse gases. Furthermore the IPCC reports are not always based on the latest science because there is an early cutoff date for considering research. Maybe there is a role for the Academies in helping the IPCC restructure its treatment of science and its review process.

The Academy also could look more closely at impacts of climate change and how to adapt to climate change. The climate argument is shifting from a focus on the science of climate change to questions about how policy makers and the public might respond to now unavoidable impacts of climate change. The Academy has done work on the consequences of climate change but it has done less work on adaptation.

The roles of technologies, economics, and policy constitute an interdisciplinary problem. The Academy has worked on such problems in the nuclear winter debate, the health impacts of ozone depletion, and other issues. It has experience with cross-disciplinary analysis and its impacts.

However, we also live in a world where communications methods are changing. Twitter, blog posts, and newsfeeds are new ways to communicate. The Academy needs to explore even more comprehensively than it has done some of these new medium of communications.

Finally, we should not underestimate the value of having the Academy public statements on science and policy related to the work done by Academy groups, even if the policy community ignores it for a while. It has proven incredibly valuable to say that the National Academy of Sciences thinks the science of climate change is strong, and the joint statements issued by the Academy with other national academies have been very effective as a way to talk about the strength of the science.

Climate Change and the Social Sciences

Naomi Oreskes, *Harvard University*

Who are the appropriate experts to evaluate a complex issue such as climate change? This question is simultaneously an issue of science and technology and also an issue of politics, economics, ethics, and values.

In recent decades, the Academy has addressed numerous issues like climate change that are not just matters of science and technology. However, to address the social, political, and economic aspects of these problems requires expertise beyond the national scientific disciplines of physics, chemistry, biology, and geology that constitute most of the membership of the Academy. The Academy acknowledges this by the inclusion of social scientists, particularly economists, in its ranks, in its Division of Social and Behavioral sciences and on NRC panels. However, despite the growing recognition of climate change as a social and policy problem, the panels that address the issues have been dominated by physical scientists.

One interesting aspect of the 1983 report *Changing Climate* is the gap between what the executive summary said and what the rest of the report said. The executive summary was largely reassuring, suggesting that the problem of climate change, if it even was a problem, was far off in the future, that humans could adapt to any changes that would ensue, and that environmental demands for regulation were a danger to free markets. These positions were potentially reasonable ones and potentially supported by evidence. However, were these claims supported by evidence in the body of the report?

Research done in the Academy archives has revealed that the summary was not actually written by the panel but by an NRC staffer, Jesse Ausubel, in consultation with William Nierenberg, the chair of the committee. There was little, if any, input from the other panelists, and we know as well from the archives that some of the panelists were unhappy with the executive summary. The entire report was severely criticized in the internal review process by reviewer Alvin Weinberg, the head of the Oak Ridge National Laboratory, who argued not only that the executive summary did not accurately represent the contents of the report but that many of the claims in it were not supported by evidence.

Whether Weinberg's critique was right or wrong is beyond the scope of today's conversation. What I would like to call attention to is whether the panel had the appropriate expertise to make claims of that sort. There was a significant gap between the expertise of the committee and the reassuring claims made by the executive summary. The key claim was that people could and would adapt easily to climate change without undue hardship. From Nierenberg's personal papers and other writings, it is clear that he was particularly moved by the argument that humans had a long history of adapting to client change in the past. He argued that there was no reason to think they would not continue to do so in the future. He did allow that some climatic effects, including sea level rise—which particularly worried panelist Roger Revelle—might drown major cities and make some coastal areas uninhabitable. However, he thought that this could be addressed by outmigration.

However, the report itself, despite its 400 pages, referred to no historical, sociological, or anthropological studies on known past migrations. The panel included no historians, sociologists, anthropologists, or archeologists who might have been able to speak to some relevant evidence. Indeed, an earlier report to the Academy on this same subject by economist Thomas Shelling, completed 3 years earlier in 1980, noted that past migrations might not be a reasonable analog to the sort of migrations that climate change could trigger because "today's political barriers hamper migration." Shelling might also have added that past migrations had been associated with large cultural, social, economic, linguistic, and demographic losses. In addition, some things, such as infrastructure, cannot be moved without very substantial economic costs, and other things, such as cultural heritage, cannot be moved at all, or at least not without significant changes in their cultural and social meaning.

Nowhere was this point addressed in the 1983 report. However, the report was widely cited in the mass media to suggest that climate change was not a very serious problem. It was also used by the Reagan administration to counter the EPA report that came out at the same time, suggesting that it was.

A second example is the 1992 report *Policy Implications of Greenhouse Warming*, which also focused considerable attention on adaptability. Given its title, one might have expected heavy representation on this panel from academic experts who could speak to adaptation, perhaps demographers, sociologists, historians, anthropologists, and maybe even psychologists or psychotherapists.

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However, a review of the 14 members of the panel reveals just one archeologist, Robert McCormick Adams, who, at that time, was the head of the Smithsonian Institution. Several of the panelists had strong political credentials. The chairman, Daniel J. Evans, was the former governor of the state of Washington, and Maurice Strong was the one-time head of the United Nations Environment Program and an architect of the 1992 Earth Summit. However, Evans' educational background was in engineering, and Strong was a businessman turned environmentalist who had started his career in the Alberta oil and gas fields.

My last example is the four-volume report, *America's Climate Choices*, issued in 2010, which again explicitly addressed the policy dimensions of climate change. Again, as explicitly noted in the title, *America's Climate Choices* might have been expected to include representation from experts who know something about choice, about how people make them, about how we often make the wrong ones from a rational perspective, and about what the consequences of our choices are likely to be. However, once again, we find a panel heavily dominated by natural scientists, starting with the two cochairs: an engineer and an atmospheric scientist. Perhaps reflecting the obviously and explicitly political character of the topic, as well as the considerable economic dimensions, the panel included a former governor, a former member of the House of Representatives, a former chief executive officer of the DuPont Corporation, a professor of law, an environmental activist specializing in environmental justice, and a public relations expert affiliated with the firm of Hill & Knowlton, which is known for its work on behalf of the tobacco industry. The panel also included an economist, a business school professor, three geographers, and a professor of sociology. Somewhat unusually for an Academy panel, physical scientists were not in the clear majority. However, many of the policy-oriented scholars, including several of the geographers, had their scholarly training in the physical sciences or engineering and the professor of sociology held a PhD in ecology.

My point here is not to say that the members of these panels were not highly distinguished people. Clearly, they were. Nor is it to suggest that the reports would necessarily have been better or more useful politically or socially had they included more experts from the social sciences. However, the strength of these reports has been on the physical scientific side, and they have a somewhat weaker scientific record on the social scientific side.

The dominance of natural scientists and academy panels is understandable given the history of the Academy, founded as it was by a group of natural scientists. The list of Academy presidents is indeed a who's who of physics and chemistry in the 20th century. Some important biologists are present as well, but no social scientists and, at least thus far, no women.

Despite the fact that we call them the social sciences and that many contemporary scientific methods and statistics were first developed in the social sciences, many natural scientists still have trouble accepting the social sciences as equally valid as the natural ones. The fact that so many members of these panels who held policy positions in academia and think tanks had their original training in science and engineering perhaps also reflects a cultural bias in the years since World War II in favor of science and engineering training and in favor of political reliance on experts whose knowledge base was presumed to be apolitical. As much research has shown, however, the presumption that physical scientific expertise can be made apolitical is, at best, arguable. Scientists, even physical scientists, struggle to create, define, and maintain a clear boundary between science and policy, between findings and recommendations, and between science and society.

Biology in Public Policy

More than twice as many of the incorporators of the Academy were in the physical sciences and technology as in the biological sciences. However, as the life sciences grew and diversified in the 20th century, so did the Academy's involvement with the issues raised by these disciplines. From the institution's 1897 report on forestry in the United States—which contributed to the creation of today's national forests—the Academy expanded its purview to the conservation of natural resources, the uses of noxious gases in warfare, food and nutrition, ecology, sex and reproduction, immigration, drug addiction, medical research, biological warfare, anthropology, and many other subjects.

From such a diverse array of potential topics, the speakers at the colloquium had to be selective. Ruth Schwartz Cowan, professor emeritus of the history and sociology of science at the University of Pennsylvania, described committees focused on population and on genetic engineering to provide examples of the tension that can arise between private and public interests. Jane Maienschein, Regent's Professor and director of the Center for Biology and Society at Arizona State University, drew on her experience as a congressional fellow to raise several prominent questions about Academy reports and the messages they seek to convey. Eliot Meyerowitz, George W. Beadle Professor of Biology at the California Institute of Technology, discussed how Academy committees are put together to achieve a balance of interests. Maxine Singer, president emeritus of the Carnegie Institution for Science, recounted some of her personal experiences with public policy debates over genetic engineering.

Public and Private Interests

Ruth Schwartz Cowan, *University of Pennsylvania*

The goal of providing advice to government requires both oversight and accountability. However, the goal of supporting good science and the people who do it requires something quite different: academic freedom, which is the freedom to do research without political control or interference. The tension between these goals is an integral part of the history of the Academy, a tension made more acute by the fact that even those of us who practice what we think of as disinterested scholarship often have social and economic interests in the outcome of policy debates.

The Committee on Population

These two themes of tension and interests can be clearly seen in two reports issued by the Academy and the National Research Council in 1963 and 1965, respectively. Both of these reports are little known today, but in the 1960s, they had a significant impact. The title of the first one was *The Growth of the World Population: Analysis of the Problems and Recommendations for Research and Training.* The second one was *Growth of the US Population: Analysis of the Problem and Recommendations for Research, Training and Service.*

Briefly, both reports came to the same conclusion: namely, that there was a population crisis in the world's future and that it was going to happen sooner rather than later. The solutions that would avert these crises, both in the world and in the United States, were contraception, more research about contraception, and more training for those who would teach families how and why to use contraception.

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Both of these reports were intended for public dissemination. Both reports were accompanied by press releases, and both were sent to all members of Congress and to the media, not just in the United States but worldwide.

Both of these reports appear to have been efficacious; there is some evidence in the archives that they were specifically requested by a few members of Congress. Beginning in 1963 and stretching into the latter part of the 1960s, Congress authorized the expenditure of funds through the Agency for International Development (AID) for the purchase of contraceptive devices and the dissemination of contraceptive information throughout the undeveloped world. Also, Medicaid legislation, which was being debated as the first of these two reports came out, ultimately contained provisions that made subsidies available for contraceptive devices and counseling at subsidized costs.

However, neither report expressed a scientific consensus among demographers. Some prominent demographers publicly disavowed them; some questioned whether a crisis was brewing either in the undeveloped world or in the United States, whereas others believed that a population problem existed but doubted whether voluntary contraception, which is what the reports advocated, could be realistically expected to solve it. The names of the committee members do not appear in either report, but the archives reveal that neither the chair nor a majority of the members were experts on medical aspects of contraception or on social aspects of reproductive counseling.

It is difficult not to conclude that the Academy's leaders in the early 1960s let their interest in creating effective partnerships with Congress supersede their interest in dispassionate science; this may be part of the reason why, a few years later, the Royal Society decided not to cosponsor a joint publication on the population crisis with the Academy. Ironically, taking the long view, this may also be a case in which poor science led to sound policy, at least on the domestic front.

Recombinant DNA

A second example of a policy debate that pitted public accountability against scientists' interests in academic freedom is the controversy about the safety of the first recombinant DNA experiments.

Between the fall of 1971 and the summer of 1973, several research groups at Stanford University succeeded in splicing the DNA from various organisms (ranging from a virus to a toad) into the bacterium *Escherichia coli*, which normally inhabits the human gut. By the summer of 1973, it had become clear that so-called recombinant bacteria had enormous industrial potential; if they had the right DNA sequences spliced into them, they could rapidly and inexpensively synthesize chemicals (e.g., human insulin) that were otherwise difficult or even impossible to produce.

It had also become clear that these experiments were very risky. At a Gordon Conference held in the summer of 1973 to assess the state of the field, so much alarm was expressed about what might happen if one or more persons was accidentally infected by these altered bacteria that the attendees voted to ask the National Academy of Sciences to convene a study committee to assess the risks of this research not only to the health of the people working in laboratories but also to the health of the public. That report was completed in the spring of 1974; it suggested a voluntary postponement of some kinds of experiments, a set of general guidelines for safe research procedures, organization of an international conference, and finally the creation of a National Institutes of Health (NIH) advisory committee to conduct research on the safety of the experiments and to issue final guidelines for containment.

In a remarkable effort to achieve transparency, the original letter to the Academy and the final report of the Academy's study committee were both made public. The Academy organized a press conference when the report was issued; it then raised money to pay for the international conference, which was held at the Asilomar Conference Center in California 6 months later. The conferees included scientists, lawyers, physicians, and bioethicists. They engaged in wide-ranging discussions of the benefits and risks of the research, as well as the moral questions that it raised—almost all of the sessions were covered by the press. The conferees also called for a voluntary and temporary moratorium on experiments until appropriate containment procedures could be established in laboratories, and they provided temporary guidelines for containment at different levels of risk until such time as an NIH study committee could agree on permanent guidelines.

As a result of this transparency, a very public discussion of the radical implications of genetic engineering—its risks and its potential benefits—ensued and has continued from that day forward. Leaving aside the freighted question of whether the creation of transgenic organisms was either wise or moral, many questions were raised at the time (and continue to be raised) about whether it was wise or moral to suspend research activity, even temporarily; whether it is wise or moral for scientists to preempt the regulatory function of governmental bodies charged with protecting public health; and whether it was wise or moral to give the members of the public any power whatsoever (which several local governments attempted to assert at the time) to influence the direction or the conduct of research.

The controversy eventually died down (particularly after a safer bacterial vector was developed), but it lives on in the writings of those who study science policy because of the questions that it raises between the ideals of public responsibility and the ideals of scientific freedom. The controversy reminds us that in a democracy, it is sometimes difficult to promote the interests of the public and the interests of the scientific community at the same time.

Conflicts of Interests in Study Committees

My last example reminds us that it is also sometimes difficult even to define the interests of the public and the interests of the scientific community.

In 1972, Congress passed the Federal Advisory Committee Act (FACA) in an effort to ensure both the independence and the transparency of expert advisory committees to the federal agencies. The act required that members of such committees should have no conflicts of interest with the deliberations being asked of the committee and that the deliberations themselves should be at least partially open to the public. As they are private institutions, both the Academy and NRC are exempt from FACA. However, after long Executive Council deliberations, a decision was made at least to require that NAS/NRC study committee nominations should take conflict of interest potential into account and that appointed committee members should be asked to sign conflict of interest statements. As wise as these policies may be, they turn out to be exceedingly difficult to administer in practice, as can be seen in one example from the 1990s.

When the Environmental Protection Agency decided to issue regulations about certain genetically modified organisms, some Academy members asked that a study committee be created to examine the proposed regulations. When, following established Academy policy, the staff members assigned to this committee made member nominations to the president of the Academy, they were very careful to exclude people who were employees of the companies that were making the organisms, as well as people who belonged to not-for-profit consumer advocacy organizations who opposed the making of those organisms.

Again, following established Academy policy, the names of the potential committee nominees were made public. This generated

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several protest letters from the not-for-profit organizations, who argued that the suggested committee was biased toward commercial interests. As a result of the protest, the Academy president decided to place one of the protest leaders who was an expert on the subject on the committee. When she replied to the invitation, she pointed out that she had a potential conflict of interest, because her organization was suing EPA over those same regulations. She was told that she was still welcome to join, which she did. Two of the original nominees recused themselves from service, because (unbeknownst to the NRC staff) they had financial interests in companies that would be affected by the regulations.

Shortly after the committee began its deliberations, two things happened. First, one of its members was asked to join the scientific advisory board of a start-up company. When this person notified the Academy of his dilemma, he was told that he could accept the invitation and also remain on the committee. Second, one of the staff members assigned to the committee resigned to take a job with a trade association in the biotechnology industry. At that point, the woman from the consumer advocacy group leaked the story of the resignation to the *New York Times* and was quoted, in the subsequent new story, as questioning the integrity of the committee. Because she had not disclosed anything about the committee deliberations themselves (to this day, the prepublication deliberations of Academy study committees are considered private and confidential), she was allowed to remain part of the committee and her name appears on its final report, issued several months later.

Thus, over the year or so of this committee's existence, many people (staff members of the NRC, all of the experts who were invited to serve, as well as the president of the Academy himself) were forced to make several difficult and subtle distinctions in the effort to decide what constituted conflicts of interest in violation of Academy policy. These distinctions were probably never easy to make, but in the years since universities and funding institutions began to emphasize technology transfer and translational science, it is, no doubt, even more difficult to find people with expertise who do not have some potential conflict of interest in study committee deliberations. Everyone involved needs to be, and often is, committed to the notion that a nonpartisan consensus can be achieved by partisan people.

The tension between the need for public accountability and the need for academic freedom can be considered a creative tension. When it works well, it helps produce public trust in expert advice. In recent years, at least, it has required that members of the Academy and staff of the NRC regularly make these difficult and subtle distinctions—and be willing to tolerate the public controversies that they can engender.

Expertise and the Roles of the Academy

Jane Maienschein, *Arizona State University*

In 1997 and 1998, I served as a congressional fellow on the staff of Congressman Matt Salmon, who was on the science committee. It was extremely valuable and educational to serve in the office of somebody who was very conservative and also interested in learning about science. Three examples illustrate what I mean.

Expertise and Authority

Who do we believe as the experts or as an authority? Is it the 3-ft-deep pile of scientific experts, or is it the book by Dixy Lee Ray, the former governor of Washington and a biologist, that Newt Gingrich was giving everybody?

When I was a fellow, the Office of Technology Assessment recently had been closed. The Congressional research service was a place to go for expertise on some things. The National Research Council was regarded as solid in some areas but suspect in others.

For example, this was a time with lots of hearings and discussion about climate change and warming. One particular hearing, which was about the impact of warming on biodiversity, had four experts and about four congressmen listening, which is more than for many hearings. The experts presented four models. At the end, one of the congressmen who were there said, "What would it take to know which of these models is best?" Each of the experts said that it would take more money for research, and in particular for their own research. The congressman pushed them by saying, "Well, which of you is the expert? You are disagreeing about what is going on here and how to understand it." The idea of what expertise is needed or what authority exists is very muddled in such cases. Although it is clear that the Academy and scientists want to be experts, they often have trouble playing that role. It is not just that people are willfully saying that they do not want to listen.

Role of the Academy

A related question is why another report is needed at times when other reports already exist. With the science education standards, for example, Project 2061 from the American Association for the Advancement of Science had already been written, yet it was important somehow for the NRC to produce another set of standards. Although there is a role for those standards, people in Congress and in the public ask why. Why are the experts at the Academy better than the experts at the AAAS? What is the difference? Can credit be shared and thereby build a larger sense of agreement?

An interesting project would be to look at changes over time in the way that Congress has received the Academy's reports. How did they receive them, what got quoted, what got cited in the Congressional Record? What was the impact of different reports? Did reports that took a long time to produce have impact later? Did a leader emerge to take a report forward?

How Science Is Presented

Finally, what is the message that science is trying to communicate? The existence of consensus around climate change or evolution is of course a strong message. However, in these cases, social scientists are not always helpful. They can talk about the social construction of knowledge and lead people to conclude that science is a constructed set of knowledge like any other constructed set of knowledge.

The messages being communicating, to whom, and for what purpose are all important things to understand.

Origins and Purposes of Academy Reports

Eliot M. Meyerowitz, *California Institute of Technology*

The committee procedures that have been instituted over the last decades for NAS and NRC reports treat conflict of interest. The first meeting of any of these committees is given over to people discussing their conflicts and biases and signing conflict of interest reports. The point of this part of the meeting, which is always taped, is not to eliminate or avoid bias or to eliminate conflicts of interest. It is to balance biases and conflicts. In this way, a consensus report has the benefit of different points of view and reflects a consensus, if one is achieved, that is acceptable to the committee members regardless of the side of a public argument where they find themselves. It also apprises the staff and the members of the committee of preexisting

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points of view that can be discussed, and it allows for an assessment of whether all sides of a scientific argument are present among the committee members.

In addition, during the report review process, a separate set of people, who are not members of the committee, consider the report in depth and make certain that the scientific statements in it are well supported and that all points of view are presented.

The social construction of scientific knowledge, at least in its strong program, holds that everyone has interests. Implicit in that statement is that everyone will act on their worst or lowest interest, which is not true. In my experience on NRC committees, people try as hard as they can to set aside their biases and listen to other people, to achieve an appropriate consensus, or at least to define those areas where it is possible to achieve a consensus.

The statements of conflict help to eliminate hidden biases, which are the ones that are most suspect. I believe that we can count on the integrity of committees to do their best not to insert their biases and personal opinions into a consensus report.

Origins of Academy Reports

The reports put out by the Academy have different origins. Some have sponsors such as government agencies, industry groups, or other groups. Others are funded by the Academy itself.

If it was possible, the Academy should do more of its own reports. This takes money, but if the Academy had an endowment sufficient to fund a dozen or so reports a year, it would allow the members of the Academy to establish what they think is important rather than just responding to government requests.

That may be opening a Pandora's box, but it would make the exercise of more interest to the members of the Academies and to the other scientists whom they represent. It also would assure more participation by members of the Academies, which sometimes is sparse.

One potential conflict of interest is the unwritten but not always unspoken rule that NRC committees should not directly, or at least severely, criticize existing government programs. This represents a conflict on the part of the NRC because it needs repeat business. It also creates a tension between the members of the committee, who often want to criticize what has gone before, and the staff, who are wise enough to know that criticisms can make a federal official stop reading a report.

An increased number of Academy reports might make it possible, at least gently, to criticize some of the government programs for which that sort of criticism is today avoided.

Audiences for Academy Reports

Finally, for whom are NRC and NAS reports written? Are they written for the sponsors? Are they written for the members of the Academies or for scientists in general? Sometimes they are at quite a high technical level, so it would take some degree of expertise to read them and understand everything.

Are they written for the journalists so that they can then take the next step and inform the general public of what is in the reports? Or is it really for the general public or for congressional staff? Perhaps different reports should be written for different constituencies.

Genetic Engineering and the Public Interest

Maxine Singer, *Carnegie Institution for Science*

According to Philippe Kourilsky, a former director of the Pasteur Institute, "On the frontiers of the unknown, the analysis of benefits and hazards are locked up in concentric circles of ignorance. Without experimenting, without taking a minimum of risk, how could one determine the reality?" That pretty well sums up the situation in the early 1970s with respect to the introduction of recombinant DNA experiments. By then, laboratory safety was a well-known concern. It was important for chemists to avoid blowing things up in the face of themselves and their colleagues. It also was important to pay attention to the spread of chemicals around the room. There were specific practices, which as a student of chemistry one learned.

Similarly, as a student of microbiology, one learned certain techniques that were designed for two reasons. One was to keep your experiment clean by not infecting your experiment with unwanted organisms. The other was to avoid infecting yourself or your laboratory mates. When the recombinant DNA situation arose, it did not arise in a vacuum about appropriate laboratory techniques.

A Dinner Party Conversation

There was a dinner party at my house that figured in the recombinant DNA story. It was when Paul Berg was first considering his recombinant DNA experiments.

At the dinner party was another friend, Leon Kass, who was very interested in issues of bioethics and appropriate behavior for scientists. An interesting conversation took place around the dinner table, only part of which I heard because I was also cooking and serving the dinner. From that conversation and from other information that came to Paul from colleagues in various places, he dropped the experiments that he had planned.

After I brought to the Academy the concerns that were expressed at the Gordon Conference in the summer of 1973, the Academy had already seen the letter that Dieter Soll and I had written on behalf of the attendees. That letter was drafted while we were at the Gordon Conference and was voted on by the members of the conference. Then the members of the conference separately voted to make the letter public. Dieter and I were concerned because some members of the conference had already left, so both of those votes were repeated by mail ballot before we sent the letter to *Science* and *Nature* to be published.

Phil Abelson, who was then editor of *Science* magazine, immediately called and said, "Do you really want to do this, because it will be public?" Because we had the vote, we told Phil that, yes, we really wanted to do this. Phil said that we were going to have years of trouble and of course, he was right. However, we published it to make it public.

Can you serve the interests of science and the public at the same time? For me, the evidence says that many people in the United States and around the world believe that it must be possible. Our country has NASA, the National Science Foundation, the National Institutes of Health, the Department of Energy, the National Oceanic and Atmospheric Administration, and public agencies, funded with tax money, that serve the interests of science. On the whole, our country and the world have benefited from the investments that the American taxpayer has made in science.

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Radiation Hazards

At 8:15 AM on Monday, August 6, 1945, a uranium-based nuclear weapon exploded at an altitude of about 2,000 ft above the city of Hiroshima, Japan. About 65,000 civilians in the city died within the first few months from burns, concussion, and radiation. Three days later, a plutonium-based nuclear bomb detonated above Nagasaki, Japan, killing about 40,000 people.

The year after the war ended, President Truman asked the Academy to conduct "a long-range continuing study of the biological and medical effects of the atomic bomb on man." Angela Creager, the Philip and Beulah Rollins Professor of History at Princeton University, described some of the history surrounding this study and the Academy's creation of the Committee on the Biological Effects of Atomic Radiation. Kevin Crowley, senior board director of the Nuclear and Radiation Studies Board of the NRC, focused on the Academy's studies of low-level radiation, both among the Japanese survivors and others exposed to radiation. John Garrick, a member of the National Academy of Engineering and vice-chair of the NRC's Committee on Lessons Learned from the Fukushima Nuclear Accident for Improving Safety and Security of US Nuclear Plants, considered the risks to health posed by nuclear power accidents. Susan Lindee, the Janice and Julian Bers Professor of History and Sociology of Science at the University of Pennsylvania, discussed some of the many ways in which the social sciences can contribute to the understanding of the effects of radiation on humans.

The Committee on the Biological Effects of Atomic Radiation†

Angela Creager, *Princeton University*

My charge today is to talk about what role the National Academy of Sciences played in research and policies around radiation hazards. While working on the history of radiological risk and protection, an enigma presented itself. Why was it not until the fallout debates of the 1950s that the US government and many scientists begin to take seriously the hazards of low-level radiation, even though many geneticists have been warning of radiological risks for decades? After all, Hermann Muller had demonstrated in 1927 that X-rays could induce mutations, and this finding was rapidly extended to other forms of radiation. Radiation also had been correlated with the appearance of cancer, especially leukemia, from the 1920s and 1930s, most tragically in the young women who were radium dial painters.

However, these two observations were rarely linked. Scientists and safety officials usually treated "genetic" effects, principally mutations, as distinct from "somatic" effects. The elevated risk of cancer was considered a somatic effect of radiation, as opposed to its genetic effects. Thus, somatic effects could directly affect the health of the individual; these were effects on the body. Genetic effects were thought to affect only one's offspring.

This separation had a long history. In the 1920s, radiation safety guidelines were set by private official bodies, such as the International Commission on X-ray and Radium Protection, or, in the United States, the National Council on Radiation Protection. These advisory bodies tended to focus exclusively on somatic effects of radiation, which they sought to control through what was called a tolerance dose for visually detectable damage. At the end of World War II, the terminology was changed to "permissible dose" in acknowledgment that even the "tolerance dose" might not be certifiably harmless. Nonetheless, a threshold mentality about safety persisted—that, below a certain level, hazards were essentially negligible.

At the end of World War II, the US government was surprisingly unprepared for the devastating effects of radiation due to its atomic weapons in Japan. The military expected, as Norman Ramsey has said, that "any person with radiation damage would have been killed with a brick first." The distinctive and disturbing effects of atomic weaponry were documented by the military's Joint Commission for Investigations of the Effects of the Atomic Bomb in Japan and subsequently by the Atomic Bomb Casualty Commission (ABCC). The NRC oversaw the ABCC, which became and remains the most important source about data on the long-term effects of radiation in humans. However, the American government did not widely disseminate this information, and Japanese accounts were censored, although some journalists did document the peculiar suffering of Japanese survivors in the American press.

The Positive Side of Radiation

However, it was not only a question of the suppression of information. Atomic energy had already developed a different, more positive, image. Although the dangers of radiation had been documented since the earliest days with X-rays and radium, so had the power of radiation to treat disease, especially cancer. Postwar optimism about the medical uses of radioisotopes and neutron sources drew on decades of efforts to harness the therapeutic promise of radioactivity, beginning with the Curies. In the 1930s, cyclotrons supplied the growing demand for artificial radioisotopes, especially phosphorous-32 and iodine-131, both of which were used clinically.

Reactors developed for the bomb project could produce radioactive materials on an industrial scale. After Americans achieved victory against the Axis Powers, many proclaimed that atomic energy would next win the war against cancer.

On May 15, 1947, Representative Everett M. Dirksen argued during budget hearings that the Atomic Energy Commission (AEC) should have a $25 million cancer program. Cancer killed "one person every three minutes," he asserted, which amounted to "72 Pearl Harbors every year." It seemed especially fitting to Dirksen that the successor to the Manhattan Project should take on the cancer problem. As he said: "If we are going to spend a few hundred million dollars in the atomic energy field to perfect an instrumentality of death, then let us take a little of that money to develop an instrumentality to preserve life."

One of the main programs that the AEC mounted to fight cancer was the production and distribution of radioisotopes. The initial plan for it was hatched by scientists within the Manhattan Project as a way to try to "free the atom" from military control, and it was the Manhattan Project that announced the program on the pages of *Science* in the summer of 1946. Over the next several years, a full-fledged radioisotope production and chemical facility was built up at Oak Ridge National Laboratory, and the supply of accessible and inexpensive radioisotopes transformed fields as diverse as molecular biology, ecosystems ecology, and nuclear medicine. Popular coverage of the AEC's program presented radioisotopes as "magic bullets" that would cure diseases, especially cancer.

This was the public face of radioactivity immediately after World War II. David Bradley blamed this mentality for the blasé attitude about radioactive contamination following the 1946 test explosions in the Pacific. As he wrote in *No Place to Hide*: "We were surprised at first to find so little interest in the Bikini tests. But we really had no right to be. Atomic energy was an uncomfortable subject. Things like John Hersey's *Hiroshima* were rough. How much more pleasant to consider the coming miracles of healing, the prolongation of

†This paper includes material from my book *Life Atomic: A History of Radioisotopes in Science and Medicine* (© 2013 by the University of Chicago Press). This material is reprinted here with permission.

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life, the days of sunny leisure which people were everywhere promising."

A Growing Sense of Danger

Some did voice concern about the dangerous effects of radiation. For example, in 1947, Paul Henshaw, who was an officer in the occupation forces in Japan and a biophysicist who went on to work for the AEC, wrote a popular article entitled "Atomic Energy: Cancer Cure or Cancer Cause?" Strikingly, however, his main concern about cancer was that the burns on Japanese survivors might turn malignant. This was based on an inflammation view of the cause of cancer, together with a related concern that cell damage resulting from high-energy radiation could cause cancer. However, in his view, low-energy radiation was entirely off the hook. As the article concluded "We know now that exposures less than one roentgen a day are safe."

Many geneticists dissented from this sunny view of the risks of low-level radiation exposure, and eventually they were heard. However, physicians and health physicists tended to hold the key government positions and articulate its policy, which rested on the assumption that there was a safety threshold for radiation exposure.

The genetic effects of radiation were addressed in 1949 by Robley Evans, a physicist known for his studies of radium dial painters. In an article published in *Science*, Evans gave a relatively reassuring picture of the genetic effects of radiation. He asserted that exposure at or under the government's permissible level would not significantly increase the mutation rate beyond the spontaneous level. Hermann Muller, whose public statements on this were clearly being rebutted by Evans' article, sent a long letter of criticism to Evans, or as Evans put it: "A few points of scientific interest, and many matters regarding personalities and prejudices."

Evans, it has to be said, had a sense of humor about Muller. I found a mimeograph of a Science Service press release about this 1949 article in the Evans papers, and it says "Queried at Bloomington, Indiana, Dr. Muller stated that he had examined Dr. Evans' manuscript before its publication, and had criticized some of its assumptions and its conclusions in considerable detail." On the press release, Evans wrote in green ink: "And that ain't all, sister!"

It was not only Muller who criticized Evans' calculations. Sewell Wright argued that the figure that Evans used for the spontaneous mutation rate in humans, 10^{-5}, which was extrapolated from pathological conditions such as hemophilia, was likely two orders of magnitude too high. He used a lower estimate based on the spontaneous mutation rate in *Drosophila* and calculated that exposures within the permissible dose could alter the incidence of mutations significantly, although perhaps not detectibly, because most mutations are recessive.

The military safety guideline at this point was set according to a doubling dose on the assumption that exposures up to that, causing double the spontaneous rate, should be considered normal and safe. Evans' numbers gave a doubling dose of 300 roentgens, whereas Wright's revised number lowered it a hundredfold to three roentgens. At this level, personnel working near the permissible exposure limits might accumulate that dose within a few months.

The AEC's own intramural research reinforced Muller's and Wright's concerns. William and Liane Russell's "mega-mouse" study at Oak Ridge National Laboratory suggested that the mammalian spontaneous mutation rate might be an order of magnitude lower than that for *Drosophila*, the number that Sewell Wright had used for the doubling dose. That would make the exposure level 0.3 roentgens for the doubling dose, well within the permissible dose set by the AEC for atomic plant workers.

Evidence from two other sources cast further doubt on the AEC's assumption that low-level radiation did not cause somatic damage. First, by 1952, the ABCC's survey of leukemia incidence among survivors in Hiroshima and Nagasaki documented a higher rate of leukemia among those individuals, and distance from the blast correlated with leukemia incidence. Even those more than 2,000 mi away (who had never shown any signs of radiation sickness) exhibited higher rates of leukemia than expected. Second, H. C. March investigated leukemia rates among physicians over a 20-year period and found a ninefold higher incidence of leukemia among radiologists than in the group as a whole.

Increased Testing

After 1950, the pace of atomic weapons testing increased dramatically. Between World War II and 1950, there were only five atomic weapons tests, whereas between 1950 and 1952, there were 26 atomic weapons tests. In addition, this is the time when hydrogen bombs were being develop and tested, which released significantly more radioactive fallout. Also, much of the testing was being shifted to the Nevada Proving Ground in the continental United States, exposing many more civilians to fallout from test blasts.

In March 1954, the AEC conducted a test of a thermonuclear weapon in the Pacific proving ground, and fallout from this Bravo shot ended up falling on a Japanese fishing boat, the unfortunately named *Lucky Dragon*. Nearly two dozen fishermen suffered injuries from the radiation exposure, and one eventually died. This was widely covered in the press, both in the United States and in Japan. However, the American government made no concessions to critics that these fishermen were suffering from radiation. Lewis Strauss, the Chair of the AEC, publically denied that fallout could be harmful to humans, animals, or crops.

Challenges followed. Geneticist Alfred Sturtevant rebutted Strauss's denial of fallout risk in a Presidential Address for the Pacific Division of the American Association for the Advancement of Science, and his address subsequently appeared in *Science* magazine. In recounting the hazards of radiation exposure, Sturtevant connected mutagenicity with so-called somatic effects. As he said, "There is reason to suppose that gene mutations induced in an exposed individual, also constitute a hazard to that individual—especially in an increase in the possibility of malignant growths, perhaps years after exposure." In comparison with the kind of radiation injuries taken into account in setting a permissible dose for exposure, there was no lower limit to the amount of radiation that might induce mutations and, in Sturtevant's words, "no clearly safe dosage."

In linking genetic effects to cancer, Sturtevant picked up on a suggestion that had been made along these lines by Muller in 1948 that radiation-induced mutations in somatic cells might be responsible for malignancies. This idea not only subverted the strong distinction between somatic and genetic effects but also raised new concern about the carcinogenic potential of fallout products such as strontium-90 and iodine-131. If there was no threshold for genetic damage, then even low doses of ionizing radiation might induce cancer.

Formation of the Committee on the Biological Effects of Atomic Radiation

The initiation of this open debate between leading scientists and the AEC made for great media coverage, and this in turn fueled public alarm. Responding to this mounting concern, the National Academy of Sciences appointed a committee, supported by the Rockefeller Foundation, to address the Biological Effects of Atomic Radiation (BEAR). There were six subcommittees focused on genetics, pathology, agriculture and food supply, meteorology, oceanography and fisheries, and radioactive waste disposal. The 1956 publication of the first BEAR report, as it was called, included reports from each of these

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subcommittees. However, the media honed in on the report from the genetics panel. As the *New York Times* headlined its story, "Scientists Term Radiation a Peril to Future of Man," reporting that "a committee of outstanding scientists reported today that atomic radiation, no matter how small the dose, harms not only the person receiving it but also all his descendants." The overall report recommended, among many other measures, reducing the maximum cumulative radiation exposure from 300 to 50 roentgens and limiting the average exposure through age 30 in the population to 10 roentgens.

Both the genetics and the pathology subcommittees addressed the health effects of radiation, but they offered strikingly different assessments. The geneticists focused on low-level doses and emphasized that "any radiation is genetically undesirable." Even small increases in radiation exposure would result in deleterious mutations or "genetic defects," as they put it. As the report went on to say, "Each of these mutants must eventually be extinguished out of the population through tragedy." The geneticists' recommendation was to "keep all of our expenditures of radiation exposure as low as possible."

As John Beatty has shown, it was not easy for the geneticists to reach consensus. Two of the geneticists on the panel—I suspect it was Muller and Wright—were not even on speaking terms, which is why Warren Weaver was brought in to chair the panel. He was not a geneticist; he was an officer at the Rockefeller Foundation with a background in statistics and mathematical physics, but he worked hard to get the geneticists to arrive at consensus.

The report from the pathology committee addressed a number of serious health problems associated with radiation exposure, but it was much more reassuring on the issue of low-level radiation. It claimed that radiation under certain levels could be "harmless to individuals." In discussing the "late" effects of radiation, namely leukemia, among Japanese atom bomb survivors and also radiologists, they insisted that these individuals had received either a nearly fatal single dose of radiation or, for those exposed occupationally, "higher than acceptable permissible dose rates." The implication was that exposure below the permissible dose rates would not result in any of these long-term effects, such as leukemia or shortening of life.

A 1957 paper by Edward Lewis bolstered the geneticists' case. He compared studies of leukemia incidence in four exposed populations: (*i*) Japanese atom bomb survivors, (*ii*) patients irradiated for a condition called ankylosing spondylitis, (*iii*) children who were irradiated as infants for thymic enlargement, and (*iv*) radiologists. The risk of leukemia caused by the various kinds of exposure was comparable, leading him to calculate a minimum estimate of induced leukemia as 2×10^{-6} per individual per rem per year. This consilience, he suggested, could be explained by the somatic mutation hypothesis for carcinogenesis. Based on his analysis, Lewis argued that the growing concentration of strontium-90 from fallout could be sufficient to raise the incidence of leukemia in the United States by as much as 5–10%. There were genuine scientific uncertainties below this calculation, but his insistence on the linear dose-dependent nature of radiological hazard was very influential.

A report from the United Nations Scientific Committee on the Effects of Atomic Radiation, published on August 10, 1958, predicted a rise in additional deaths from leukemia worldwide due to radioactive fallout, just as Lewis had. The increase in radioactivity they pointed out was slight, only about 5% of the total radiation received from natural sources. However, the report supported the assumption that even small increases in radiation could still lead to measurable increases in cancer.

Strikingly, the BEAR committee on pathological effects issued a commentary on the UN's report. The panel specifically attacked the somatic mutation theory, writing that "while somatic mutations may be included among these effects, it seems doubtful that a strict linearity analogous to that seen in the genetic effects of radiation is as likely to hold in the case of these conditions."

Part of the disparity between how geneticists and the individuals on the pathology committee viewed low-dose radiation reflected disciplinary orientation. It is perhaps not surprising that physicians or health physicists resisted seeing the complexities of radiation-induced cancer reduced to mutations, and there are problems with the somatic mutation theory, especially for diploid organisms. However, the two panels were also different in the nature and the extensiveness of their relationships to the AEC, with the pathological effects panel populated largely by current and former Manhattan Project and AEC employees.

Warren Weaver, who headed the genetics panel through the publication of the 1956 report, noted that there was a conflict of interest behind the deliberations. As he wrote confidentially to Detlev Bronk in a letter I saw in the NAS archives: "Incidentally, and quite confidentially, do you feel entirely comfortable about the degree of commitment and (perhaps unconscious) loyalty to the AEC that exists in the pathology group? I do not."

AEC officials and many of its researchers resisted giving up the threshold concept or accepting the somatic mutation theory. A 1958 paper from Argonne National Laboratory gave the results of a study in which mice were exposed to various doses of strontium-90. The expected effects of life shortening and leukemia were seen, but the mice that received the lowest dosage did not show any of these effects. The scientist Miriam Finkel argued that a threshold for strontium-90 hazards existed, one that was well below the human exposures to fallout. This was challenged by Linus Pauling and others, and in response to the debate, Argonne's director Austin Brews went on record as asserting that the theory of linearity remained unproven.

The genetic viewpoint eventually prevailed. As the 1972 BEIR report stated (by which time the name of the committee had shifted to be the Biological Effects of Ionizing Radiation), "Until recently, it has been taken for granted that genetic risks from exposure of populations to ionizing radiation near background levels were of much greater import than were somatic risks. However, this assumption can no longer be made if the linear non-threshold relationships are accepted as a basis for estimating cancer risks." The somatic mutation theory went on to become, as one book on cancer biology puts it, the "prevalent theory of carcinogenesis."

The BEAR Committee in Retrospect

The National Academy of Science's BEAR committee played a crucial role in this shift, both as a discussion forum for practitioners of the relevant science and as a source of information to both the US government and to the American public about the consequences of that knowledge. One might see this history as a story of triumphalism, of marginalized geneticists seizing the political opportunity provided by the BEAR report to get out their perspective on radiation hazard. This is no doubt true, but the perspective that they had on mutational damage was far from complete. The discovery of DNA repair in the 1960s showed that mutations were not necessarily irreversible, and the assumption that radiation damage is linearly dose dependent at very low exposures remains controversial.

Members of the successor to BEAR, the Biological Effects on Ionizing Radiation committee, were famously unable to reach consensus about the hazards of low-dose radiation exposure in the report that they issued in 1980. Moreover, the shift in the 1970s to analyzing radiation hazards in terms of cost-benefit analysis further complicated efforts to assess what risks were acceptable by rendering a political issue in largely economic terms, which is

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apparent in the correspondence behind funding the BEIR reports in the 1970s.

The scientific committees appointed by the National Academy of Sciences to address these problems also were not free of entanglement with affected government agencies, nor could they resolve the most important controversies. However, they did bring these controversies to public attention, which itself is an important legacy of the Academy for 20th-century American science and politics.

Understanding Radiation Risks in Humans

Kevin Crowley, *National Research Council*

Much of the scientific research on radiation effects in humans is being driven by two questions: what are the effects of ionizing radiation on human health and what are the biological bases for these effects? These questions have important implications for human well-being and governmental policies for protecting people from the potential harms arising from radiation exposure.

These questions are especially pertinent for exposures to ionizing radiation at doses that people typically encounter in their lives. These exposures are sometimes referred to as "low-dose exposures," generally understood to mean radiation doses lower than about 100 mSv.

Data on radiation effects in humans were just beginning to emerge at the time the BEAR reports were issued. The most important data on radiation effects in humans are from studies of survivors of the 1945 atomic bombings of Hiroshima and Nagasaki. These studies were begun by the Atomic Bomb Casualty Commission in 1947, and they are being continued today by the Radiation Effects Research Foundation (RERF). The Academy established ABCC at the request of the US government, and it has a longstanding cooperative agreement with the US Department of Energy to provide scientific support to RERF, primarily by using US scientists to work at the foundation.

ABCC/RERF has been carrying out long-term studies on three survivor cohorts. The Life Span Study is designed to investigate long-term effects of radiation on causes of death and incidence of cancer. This cohort includes about 120,000 residents from Hiroshima and Nagasaki. The In Utero Exposed cohort was designed to investigate the effects of radiation on fetal development and long-term health. It consists of about 3,600 subjects. The F1 cohort was designed to investigate genetic effects of radiation on the offspring of survivors. It consists of about 77,000 subjects.

The ABCC/RERF studies are often referred to as the gold standard for radiation epidemiology studies, because of their large size, decades-long duration, inclusion of both sexes and all ages, wide range of individual radiation exposures, and careful design and execution.

Radiation Effects Among Survivors

Japanese atomic bombing survivors received a wide range of doses from the atomic bombs because of their locations and shielding conditions. For the Life Span Study, most of the survivors in the cohort were located between 1 and 3 km from the bomb hypocenter. Relatively few people within a 1-km radius of the bomb survived the blast and radiation.

The Life Span Study cohort shows a clear increase in mortality from cancer in the decades following the bombings. Excess deaths from leukemia peaked about 5 years after the bombings. Excess deaths from solid cancers started rising about 10 years after the bombings, and they are still rising and likely will peak in the next decade.

Excess deaths from noncancer disease, primarily cardiovascular disease and stroke, are also occurring in this cohort. The peak in cardiovascular disease is anticipated to occur sometime after the peak in solid cancers. To date, the F1 cohort, which are the children of survivors, shows no evidence of increased genetic risks from radiation exposures.

Exposure to ionizing radiation increases the risk for most types of solid cancers. The magnitude of the risk varies by cancer type. Cancers of the esophagus, stomach, colon, liver, gall bladder, lung, breast, ovary, and bladder all have statistically higher risks.

Cancer risks also are age dependent. Younger persons are more sensitive to radiation cancer induction than older persons, and their risks persist for a lifetime. Females also have a higher risk than males for some types of cancer, particularly thyroid cancer, lung cancer, and of course uterine and breast cancer.

The BEIR Studies

ABCC/RERF is the most important source of data for radiation health studies carried out by the Academy. These studies, which are requested and funded by the US Environmental Protection Agency, are referred to as the Biological Effects of Ionizing Radiation (BEIR) studies.

Seven BEIR studies have been carried out to date, with the most recent published in 2006. A key objective of these studies is to develop quantitative estimates of risk for exposure to low levels of ionizing radiation. These risk estimates are used by federal agencies to set radiation protection standards for workers and the general public.

For a single 100-mSv exposure delivered at a low dose rate, the BIER VII estimates that risks of developing cancer over a lifetime would increase by about 1%. However, there are sex differences in the risk, and there are large uncertainties in the estimates. Also, these estimates are for cancer incidence, with the risk for cancer mortality about one half of these values.

The 1960 Radiation Protection Guidelines, which were developed based on BIER report findings, established a 5-mSv annual limit for individual exposures, exclusive of natural background. Allowable limits have been reduced since 1960 because of the information provided by ABCC/RERF and the NAS. As an example, the annual limit for individual exposures from nuclear fuel cycle facilities, which include nuclear power, is now about 0.25 mSv. This is a 20-fold reduction compared with in the 1960 radiation protection guideline limit.

Much remains to be learned about radiation risks in humans. The shape of the dose–response curve below 100 mSv continues to be an important scientific and policy question because worker and public exposures occur at low doses. The BEIR I committee used the linear no threshold hypothesis (LNT)—that is, a linear relationship between radiation exposure and risk that extends to zero exposure and zero risk—for pragmatic reasons and not because it was indicated by available scientific evidence. The BEIR VII report (the most recent BEIR study) noted that statistical limitations make it difficult to evaluate the shape of the dose–response curve at low doses. Nevertheless, the report concluded based on a review of biology data that LNT applied at these low doses.

Risks of Nuclear Power Systems

B. John Garrick, *NRC Committee for Improving Safety and Security of US Nuclear Plants*

Very large inventories of radioactive material pose both safety and environmental risks, with nuclear power plants being the primary example. The focus of nuclear plant risk studies is on the likelihood of high-consequence events, such as severe accidents that might occur from within the facility, or a severe natural, external event such as the great eastern Japan earthquake that occurred on March 11, 2011. In turn, the credibility of

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quantitative risk assessment depends primarily on two factors: the ability to identify events that lead to radiation exposure threats and the ability to represent the health and safety effects resulting from an exposure, together with their likelihood of occurrence.

More than 30 years ago, I led a full-scope risk assessment that calculated such measures of risk as early fatalities, injuries, thyroid cancers, latent cancer fatalities, whole body dose, and property damage and evacuation cost. Such plant-specific full-scope assessments have not been performed since the 1980s. To be sure, there have been risk assessments, but they have been limited in scope.

An important question is how the current state of knowledge should affect attempts at quantifying the risk of complex nuclear systems. The rules of engagement of probabilistic risk assessments favor integrating or fusing the various dose–response hypotheses probabilistically, based on their credibility, to evolve an evidence-based model. That way, the evidence supporting linear and nonlinear threshold and nonthreshold hypotheses is represented in the dose–response model based on scientific principles. Included in this fusion process would be such dose–response hypotheses as LNT, threshold models, and hormesis models.

Such an approach would seem appropriate, especially given that the BEIR report notes that there are still significant uncertainties about the mechanisms that lead to adverse health effects following exposure to ionizing radiation, especially with respect to low levels of radiation. Basing risk assessments on just one of several hypotheses is not in keeping with the spirit of quantifying the risk.

Changes in modeling might lead to higher estimates of risk than estimated in the past. One is the consideration of noncancer health impacts, such as radiation-induced chromosomal aberrations that could lead to adverse health effects. Neurological damage is another health effect that has a very different biology than cancer. Another frequently mentioned health effect that is not generally modeled and probably should be is the psychological consequences of being exposed to low doses of radiation, a factor that could be important in formulating nuclear plant evacuation strategies. In fact, stress-related phenomena in the aftermath at Fukushima, some due to extended evacuation and relocation, may have resulted in a significant number of deaths.

On the other hand, changes in our state of knowledge could lead to lower estimates of nuclear facility risk. Probably the biggest impact on reducing estimates of nuclear power plant risk has very little to do with the health effects model. The evidence from the accidents that have occurred to date indicates far more confinement capability of the radioactive material during the progression of the accident, even in the presence of degraded containments, than was incorporated in earlier risk assessments. Of course, the next accident could be a different story, and we have to account for that in our probabilities. However, for the four light water nuclear power plants that have melted their cores—Three Mile Island and the three in Japan—there have not been acute radiological consequences, which to the nuclear facility risk professional is a major and positive surprise. To be sure, we have yet to determine what the latent effects might be.

Probabilistic Risk Analysis

My judgment is that had we known then what we know now: the uncertainty spread would be somewhat less than shown in earlier risk assessments. However, I suspect that the central tendency parameters would not change much because of offsetting effects. A probabilistic framework can be an effective approach for providing resolution between what is known and not known, and the various states of knowledge in between. Quantifying the uncertainties probabilistically greatly facilitates the calibration of states of knowledge of fundamental processes, such as the biological effects of low-level radiation. It allows for a systematic process to integrate and fuse all of the hypotheses considered into a representative model without having to choose one over the other.

The totality of the evidence should determine the dose–response model. The BEIR studies have been enormously beneficial in providing reference material on the state of the relationship between exposure to ionizing radiation and human health. However, in my opinion, the information would be much more valuable had the BEIR committee adopted a probabilistic framework to process their findings and present it more quantitatively, with the supporting evidence that they considered.

The goal of the risk sciences should not be just to bound the results of risk analyses or even to seek conservative results. The goal of the risk scientist should be to present the truth about the results, which means quantifying the uncertainties and making transparent the supporting evidence and our confidence in the results.

Radiation Risks and the Social Sciences

Susan Lindee, *University of Pennsylvania*

The studies of the Atomic Bomb Casualty Commission never included attention to psychological or social effects of the bombings. The research groups in Hiroshima and Nagasaki did not document the consequences for society of so much death and destruction. Not until Robert Jay Lifton in the 1960s began to interview the survivors was there even an effort on the part of any American scientists to try to understand the psychosocial dimensions of the bombings. However, one of the key justifications for studying the survivors at Hiroshima and Nagasaki was to provide insights to American planners for civil defense. The ABCC was at least partly intended to help American populations be prepared for a future nuclear war. It is important to recognize that nuclear theorists in the 1950s generally expected nuclear war to happen. Anger at the Soviet enemy, and fear of a Soviet attack, shaped decisions about studies of the biological effects of radiation. Because genetic effects were so important in these debates, the work of the National Academy of Sciences played a major role not only in studies of the general biological effects of radiation but in the development of the science of human genetics. The atomic bomb led to significant government support for human genetics research and it justified major field studies with isolated populations in the 1950s and 1960s. Such "primitive" groups were seen as unexposed to radiation and therefore a source of data on what the "normal" mutation rate was in human populations.

Most prominent geneticists and environmental scientists in this period were supported by the Atomic Energy Commission. However, the notion that AEC funding somehow produced a particular scientific conclusion about radiation risk is not accurate. H. J. Muller received significant funding for about a 15-year period from the AEC, even as the AEC was attacking him publically. Similarly, most of James V. Neel's research was funded by the AEC, and Neel was clearly engaged in a very serious effort to accurately assess the genetic effects of radiation. He personally had a strict sense of a firewall between his results and the expectations of the leadership at the AEC.

Radiation and Genetics

In a sense, then, human genomics arises out of the question of the genetic effects of radiation. The first IBM conference on mapping genes was in 1959, and Victor McKusick was suggesting mapping the human genome in the 1960s.

Radiation studies perfectly exemplify a concept developed by Ulrich Beck. He proposed that risk and uncertainty have become the fundamental organizing principles in society and that scientific tools are

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commonly now used to study risks created by scientific discovery.

Thus, nuclear weapons and nuclear energy create risks that can be assessed using a different suite of sciences and a different kind of technical knowledge. Scientists are asked to conduct a very strict and interesting cost–benefit calculus of technology and risk, and many different kinds of scientific expertise are involved. The distribution of these risks is lumpy, of course, with some people at high risk and some people not at risk.

The Academy's contribution to science and public policy is not so much about victories or failures. It is about respect for a process that is carried out with integrity. It is a messy process that involves multiple voices, conflicting voices, lumpy consequences, uncertainty, risks at multiple levels, and data that do not speak in a crystal clear way. These uncertainties have been significant in terms of radiation risk.

When Neel, Muller, and their peers were struggling to understand these risks, it was common for those who worried about radiation to be called emotional. John Gofman was called an "opera star" by one of the AEC commissioners. Muller was commonly called hysterical or overly emotional. Being overly concerned about radiation risk seems to have been somehow irrational, or even feminine. However, in retrospect, the hardcore cold warriors were also emotional. The numbers of bombs produced in the course of cold war—far more than were needed in any imaginable future war—reflected the anger and fear (however legitimate) that they experienced. Emotion is present on all sides of this debate; there is no way out of it.

Neutrality and disinterestedness remain important and appealing in the scientific community. However, today scientists also face similar complexities in which perspectives on all sides are animated by emotions. Perhaps a new vocabulary is needed regarding emotion and neutrality. Thinking about these questions of science and public policy can help us think about how the history and future of the National Academy of Sciences, which to a remarkable degree has been in the middle of the messiest aspects of 20th century science.

Biodemography and Vital Statistics

Although the Academy focused largely on the physical sciences for most of its first 50 years, following both World Wars, its mandate broadened into the life and social sciences. By 1976, the eight divisions of the NRC included three grounded firmly in the social sciences: the Assembly of Behavioral and Social Sciences, the Commission on Sociotechnical Systems, and the Commission on Human Resources.

Biodemography and vital statistics have been important components of this increasing involvement with the social sciences. At the colloquium, Margo Anderson, Distinguished Professor at the University of Wisconsin-Milwaukee, described the Federal Statistical System and the creation of the Committee on National Statistics within the NRC. Robert Hauser, executive director of the NRC's Commission on Behavioral and Social Sciences and Education, delivered a talk on the Committee on Population, which initiated a traditional of groundbreaking work on demography at the Academy. Michael Hout, professor of sociology at New York University, touched on the Committee on National Statistics' influences on social science research. Kenneth Prewitt, Carnegie Professor of Public Affairs at Columbia University, explored the extent to which the social sciences can be demonstrated to have influenced public policy.

The Federal Statistical System

Margo Anderson, *University of Wisconsin–Milwaukee*

The Federal Statistical System consists of the federal government agencies that produce official statistics. There are 98 federal agencies that produce statistics, with about 40% of the expenditures in 13 lead agencies. They by and large create and codify the major classification systems of the social sciences. They set data stewardship and confidentiality standards for the social sciences. They also archive, preserve, and distribute statistics free to the public. The infrastructure of the social sciences in fields such as demography, political science, consumer behavior, labor force dynamics, income and wealth, education, and crime and justice depends on data produced in the Federal Statistical System.

The United States has a decentralized statistical system that is embedded in the American Constitution. This system has two legs. One is based on survey data, with the foundational instrument being the census. Article I, Section 2 of the Constitution required that "Representatives and direct taxes shall be apportioned among the several states which may be included in this Union, according to their respective numbers." The nation has had 23 decennial censuses since 1790, and the US Census Bureau has grown into the nation's premier survey research organization.

The second leg of the statistical system derives from administrative data systems. These are based on slightly different provisions of the constitution, particularly the requirement that expenditures and accounts of public money shall be published (Article 1, Section 9) and that the President is required from time to time to present the state of the union to Congress (Article 2, Section 3).

Those provisions meant that very early in the development of the American state, administrative statistics were both compiled and published. By 1810, statistical compilations were being produced, and the administrative structures existed to collect, codify, and standardize data.

During the 19th century, the science of statistics grew inside the government and was professionalized. The American Statistical Association was founded in 1839, a generation before the Academy, with a foot in both the mathematical and the social sciences. By the time the NRC was established in 1916, the Census Bureau was a permanent agency in the Commerce Department, collecting not only the population census but censuses of agriculture, manufacturing, government operations, religious organizations, and finance.

A History of Discovery and Innovation

One of the great discoveries of the Federal Statistical System was just how fast the American population was growing compared with its comparator states in Britain and France. Rapid population growth also put a strain on the tabulation of the census results. By 1880, when the American population topped 50 million, the tabulation was still done by hand by legions of clerks. In 1890, the Census Office introduced machine tabulation. The handwritten answers on the census questionnaire were converted to punch cards, and then the punch cards were counted. The company that built this technology, Hollerith's, turned into IBM, and the Census Bureau and Federal Statistical System became innovators in machine processing.

On the administrative statistics side, the Treasury Department's reports of tax revenues and expenditures became the basis for more elaborate time series reports on the American economy. In 1878, the Treasury Department introduced The Statistical

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Abstract of the United States and began to compile data annually to provide the record of all sorts of domains of American life. Data on population, finance, commerce, agriculture, exports, mining, railroads, telegraphs, immigration, education, and public lands were all published and developed into time series collections thereafter.

The leaders of the Federal Statistical System became major leaders in American science as well. For example, Academy member Francis Amasa Walker was census director in the 1870s and 1880s, president of MIT, president of the American Statistical Association, and the founding president of the American Economic Association. The member biographies of the Academy in the 19th century include many people who crossed disciplinary lines in this more amorphous period in science.

Efforts at Centralization

By the early 20th century, the US government produced a wide variety of high-quality statistics, both from the census and periodic surveys and from administrative statistics. Presidents from Theodore Roosevelt to Franklin Roosevelt proposed administrative streamlining and consolidation of the activities of the myriad agencies that produced official statistics. These efforts failed as Congress or supporters of particular agencies resisted administrative reform. Franklin Roosevelt finally achieved a modicum of central coordination in the early 1940s with the creation of the position of Chief Statistician in the Bureau of the Budget, Executive Office of the President. Individual statistical agencies would not be brought under the authority of the Chief Statistician, but as head of the Office of Statistical Standards, he had the authority to approve all data collection forms within the federal government. That power provided the capacity to eliminate duplication, standardize procedures and classification systems across agencies, and encourage technical innovations in data collections. In the 1950s and 1960s, statistical agencies introduced computer processing and management of statistical data, starting with the Census Bureau's use of the Universal Automatic Computer (UNIVAC) for the 1950 census. At the time, the individual agencies each built their own systems.

Further efforts at centralization were proposed in the 1960s, when the potential for saving money and fostering research by consolidating the myriad computer databases attracted the interest of the Budget Bureau and academic social scientists. Congress, however, did not see the value of building such a "national data center" and raised significant privacy concerns. The proposal was quietly withdrawn. However, Congress and the President did agree to create the President's Commission on Federal Statistics of Wallis Commission, which recommended the establishment of the Committee on National Statistics (CNSTAT) in the National Academy of Sciences. At the same time, Phillip Handler was becoming the Academy's new president, and one of his initiatives was to increase the presence of the social sciences in the Academy. Since its founding, CNSTAT has produced 242 reports, 181 of them in the last 20 years. If one looks at some of the major technical innovations in the federal statistical system in the last generation, it is hard not to see the stamp of CNSTAT reports on the work.

The federal statistical system remains decentralized, but the creation of CNSTAT has provided the venue for the leadership of statistical sciences to work with and support the further development of the scientific innovation and offer policy guidance.

The Committee on Population

Robert Hauser, *National Research Council*

In the early years of the Committee on Population (CPOP), much of its activity focused on population growth, especially on fertility control and the relationships between population growth and economic development. However, despite the continuation of rapid population growth in some parts of the world, and especially in Sub-Saharan Africa, there was a sharp decline in demand for NRC work in this area. Some of the factors in this decline were the success of family planning programs in some parts of the world, a replacement of concerns about population growth and family planning per se with those of women's empowerment and economic growth, and changes in the research agenda of the Agency for International Development (AID) and the major foundations that once supported research on population growth and policy.

For example, despite projections of continued growth in the world's population to 10 billion, and of increasingly deleterious effects of global climate change, the Division of Behavioral and Social Sciences and Education has been unable to win support for any large-scale study of sustainability and economic conditions in the context of these projections. Instead, with guidance from Richard Suzman, director of behavioral and social research at the National Institute on Aging, CPOP has increasingly and productively focused on issues related to the causes and the consequences of population aging. This work began with the seminal edited volume *The Demography of Aging*, which was published in 1995. Since then, CPOP has produced a mix of consensus reports, edited volumes, and workshop reports, now numbering almost three dozen.

The Science of Population Aging

Four themes of the series have had enormous influence on the science of population aging. First, CPOP's work has led to increasing interdisciplinary studies of population aging and, in particular, to the integration of biomedical, genomic, economic, social, and psychological research. The first contribution to this theme was an edited volume called *From Zeus to Solomon* published in 1997, which dealt with such diverse topics as the role of the elderly in other species and among human societies past and present, the contribution of evolutionary theory to our understanding of humans, and the potential for collecting genetic material in household surveys. This work and its sequels are now complemented by current study of new developments in biodemography.

Second, CPOP's contributions have provided a series of motivating, illustrative, and instructive reports on the inclusion of biological measures in social surveys. The lead contribution was a volume called *Cells and Surveys: Should Biological Measures Be Included in Social Science Research?* published in 2001, and most recently, *Conducting Biosocial Surveys: Collecting, Storing, Accessing, and Protecting Biospecimens and Biodata*, published in 2010.

Third, with leadership from the National Institute on Aging, CPOP has contributed to the development of an international cohort of longitudinal biosocial surveys of aging and health. More than two dozen such surveys around the world are located mainly in and around Europe as well as the United States. In the recent past, CPOP has conducted workshops and produced reports that encouraged the development of such surveys in Asia, and a project now under way at DBASSE will undertake a similar effort, focusing on aging in Latin America.

Fourth, CPOP has addressed the factors in US longevity and mortality. Here the two key reports are *Explaining Divergent Levels of Longevity in High-Income Countries* in 2011, and in 2013, *US Health in International Perspective: Shorter Lives, Poorer Health.* At ages above 50, not only does life expectancy in the United States lag behind that in many other developed nations, but

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the growth in life expectancy falls short in international comparisons. Moreover, at all but the oldest stages, in almost every population group, the United States lags far behind many other nations, both in morbidity and in mortality.

Social, behavioral, and environmental factors dominate strictly biological conditions in accounting for observed lags in morbidity and mortality. Nor is the US system of medical care as important as social, behavioral, and environmental factors in accounting for the observed lags in morbidity and mortality. The two major consensus studies in this area, both conducted via comparisons between the United States and other nations, have thoroughly debunked the widespread belief that the United States is a world leader both in health and in longevity.

The Committee on National Statistics

Michael Hout, *New York University*

Until the 1960s, the Census Bureau and other federal statistical agencies gathered data and produced statistical abstracts and census reports. However, details about individuals were not available because of privacy concerns.

Beginning in the 1960s, the Census Bureau and other federal agencies figured out ways to release to the research community what are called microsamples: anonymized datasets with all of the information about individuals except their name and with enough geographical details stripped out so that where they are cannot be imputed. These anonymized data files have revolutionized the population sciences, including demography, sociology, and labor economics. By the 1970 census, for example, 1 in 100 samples from long form respondents were available with different information stripped out for use in different contexts. At that time, a 1 in 100 sample from the 1960 census also was released with data from an earlier census released subsequently.

These datasets were hard to compare until an institution called IPUMS.org was established at the University of Minnesota to integrate the datasets. The Integrated Public Use Microdata Series (IPUMS) collection now includes all of the censuses from 1790 to 2010. Most of the Current Population Surveys (the monthly unemployment surveys) have been machine coded and anonymized and are available through the IPUMS.org website.

These ideas quickly began to spread, so that other countries began releasing microsamples. The IPUMS website now has 238 samples from 74 countries in anonymized microsample form. Other organizations have compiled other kinds of social science data from across the world and have harmonized them in ways that make it possible to use a multicountry dataset as if it was one study done in all of the countries simultaneously.

An important aspect of this work has been the linkages created between some of these data files and administrative records, so that data from individuals about work can be linked to data about their employers or about their state welfare system. These kinds of data linkages can lead to disclosure of who the person is, and so they are not publically available and have to be accessed at a Census Bureau data center. This protects the privacy of individuals while giving social scientists access to all sorts of these data.

The Committee on National Statistics has been crucial in providing advice on issues such as disclosure analysis, in which the data are tested to make sure that individuals cannot be identified. By speaking up on behalf of the user community, the committee has helped gain access to more and more of these important data.

Major Advances

The release of these microsamples has produced a revolution in understanding of who works in the United States. The labor force participation of women and the withdrawal from the labor force of older Americans represent tremendous societal changes, and the data have helped reveal the processes involved in the decisions that members of households make about going to work or staying home given such factors as pensions and access to other people's income. Access to the census microsamples have also made it possible to calculate correlations between attributes of individuals within households, and labor force participation, producing tremendous progress in the sociology of the family.

Almost everything known about income inequality in the United States also comes from these data sources. Some is reported by the census, but the details are based on detailed analysis of microsamples by sociologists, demographers, and labor economists.

Finally, the 1973 study of David Featherman and Robert Hauser on social mobility was based on a supplement to the March Current Population Survey of 1973. That study extended a 1962 study and set the tone for the other releases of microsample data. To this day, it remains a landmark study of social mobility in the United States.

Failures to Understand the Use of Science in Public Policy

Kenneth Prewitt, *Columbia University*

Since its modern origins in the late 19th century, American scientific inquiry about human behavior and social structures has also included research focuses on nation-building tasks: strengthening democracy, promoting economic growth, securing national security, and improving social welfare. These two social science projects, the first deepening scientific understanding and the second contributing to informed policy choices, have continuously fed on each other.

This was evident as early as studies of what were labeled the "social problems" in the 1880s: labor relations, immigration, urbanization, crime, and so on. The link between knowledge and policy was sharpened by an active partnership with government agencies in the first World War, again in the depression years, and, more extensively, during the Second World War. The tight links between science and national goals was taken to new levels with the arrival of Big Science at midcentury. For the social sciences, this led to a policy enterprise designed to deliver the results of a steadily stronger science to policymakers. The policy enterprise included research universities of course, but also specialized institutes, think tanks, foundations, contract houses, consultants, and public policy schools that trained the personnel for this enterprise. A specialized vocabulary emerged: evaluation research, social experiments, evidence-based policy, social indicators, performance metrics, and so on.

A 1978 NRC report, *Knowledge and Policy: The Uncertain Connection*, assessed this enterprise. It identified a number of steps taken by the government to connect scientific knowledge and policy. However, the report was unable to document how well the connections were working; hence, the uncertain in its title. It concluded "We lack systematic evidence as to whether these steps are having the results their sponsors hope for."

This was 1978, following a decade of social experiments, large government-funded studies, and impressive advances in social science method and theory. Social scientists had, it was claimed, helped design great society policies. Other social scientists had documented unintended consequences and perverse incentives associated with these policies, and, it was claimed, helped dismantle them.

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However, a careful Academy assessment of the formulation of evidence-based policy concluded, regrettably and ironically, that there was little research knowledge about when, how, and even whether scientific findings were being used in policy-making.

Three and a half decades later, the NRC was again asked to assess the place of scientific findings in policy-making. This 2012 report, *Using Science as Evidence in Public Policy*, found that the policy enterprise concerned with bringing scientific findings to bear on policy had greatly expanded. (I chaired the panel responsible for this report and was its lead editor.) Nonetheless, the 2012 report reached the same conclusion as its 1978 predecessor. Although research results were certainly being used as evidence in policy-making, and equally certainly were being ignored or misused, all we have is anecdotal testimony. What we don't have is anything that could be called a "theory of use" or even much in the way of theoretical statements taking into account that the use of science is undoubtedly highly context dependent.

Using Science as Evidence in Public Policy reached another conclusion. Too much effort was being spent proposing typologies of use, arguing the virtues of evidence-based policy, and debating whether there are hierarchies of evidence. There was too much focus on the production side and too little attention to the consumption side. To understand the how, when, and why any science is used in public policy means getting inside of the heads of the people who are making policy. Whatever the nature of the science—engineering, biology, mathematics, chemistry, or economics—its use is necessarily a social phenomenon. Use and nonuse occurs in social settings, where the players negotiate, compromise, deceive, mislead, forget, misunderstand, and become distracted. The social sciences have the tools to look systematically at these social settings from the point of view of whether science is being used or not, and if not, why. The engineer can predict that the bridge will collapse unless stress analysis has been correctly applied; the epidemiologist can say that a disease will spread unless basic public health principles of sanitation are followed. Each can say that their science should be used, but neither is trained to study whether it will be used. This is the task of social science: cognitive psychology, political science, behavioral economics, and the sociology of decision-making and group dynamics. Although social science has relevant methods and theories, it has not made "the use of science" an object of analysis. Until it does so, cries and complaints that science is ignored, or boasts about its importance and impact, will rest more on anecdote than evidence.

Computing and Information

Of all of the areas in which the Academy has played a role in building the infrastructure for modern science and technology, none has been as influential as computing. From its efforts to improve ballistics to the development of the Internet, the Academy has served as a vital intermediary among government, academia, and industry in motivating research and guiding the direction of the field.

Nathan Ensmenger, associate professor of informatics and computing at Indiana University, detailed the Academy's early involvement with computing, which grew out of the institution's publication of mathematical tables between the wars. Robert Kahn, president and chief executive officer of the Corporation for National Research Initiatives, discussed some of the early days of electronic computing and how difficult it is to predict the future of the field. Janet Abbate, associate professor of science and technology in society at Virginia Tech, drew from computing several broad lessons for the nation's investments in science and technology. David Farber, Distinguished Career Professor of Computer Science and Public Policy at Carnegie Mellon University, pointed to several problems that are likely to extend the Academy's influence in computing.

From The Aberdeen Proving Ground to the Internet

Nathan Ensmenger, *Indiana University*

A prominent myth in the history of computing is that innovation in the industry has been driven by commercial firms and that government and academia have played very little role. Indeed, the dominant narrative in many popular histories of computing is that the really exciting and important developments often originate with individuals, and not just individuals, but a very specific kind of individual—slouchy young men with countercultural tendencies, unconventionally educated, unruly, and undisciplined. These are the anti-scientists, the anti-bureaucrats, and the anti-establishment. In the techno-libertarian milieu of Silicon Valley, government officials, elite academics, and other expert authorities are seen as barriers and not opportunities.

Historically speaking, nothing could be farther from the truth. The influence of the Federal Government, particularly the United States military, is everywhere apparent in the history of computing. From the Electronic Numerical Integrator and Computer (ENIAC) to the Internet, the visible and invisible hand of government has dramatically shaped scientific, social, economic, and political developments in electronic digital computing.

The Committee on Mathematical Tables and Other Aids to Computing

In its role as advisor to the US government, the National Academy of Sciences has changed the course of the history of electronic computing. This story begins more than three decades before the invention of the first electronic digital computers. During World War I, a Princeton mathematician, Oswald Veblen, conducted mathematical research as a captain in the Navy Department of Ordinance. As the historian David Grier has documented, Veblen's work "laid the foundation for the NRC's Committee on Mathematical Tables and Other Aids to Computing (MTAC)," which was arguably the first scientific organization dedicated to research and development in the computational sciences. Veblen commanded the division of experimental research at the Army's new Aberdeen Proving Ground in Maryland. This was a massive operation that would ultimately occupy more than 35,000 acres along the Chesapeake Bay, at a cost of more than $73 million. Veblen's job at Aberdeen was to produce ballistics tables for use in naval artillery. To accomplish this task, he used more than 60 mathematicians, most of them young faculty members or graduate students. This wartime experience helped establish them as leaders in the mathematical community. As one member of the group, Norbert Weiner, remembered, "For many years after the first world war, the overwhelming majority of significant American mathematicians was to be found among those who had gone through the discipline of the proving ground." In this way, the NRC and NAS provided the breeding grounds for new kinds of practitioners, for graduate students, and for emerging scientists.

Two direct lines can be drawn from the work of Veblen and the other mathematicians

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at the Aberdeen Proving Grounds to the origins of modern electronic digital computing. The first runs through the publication of the NRC mathematical tables and other aids to computation and the foundation of the first journal of scientific computation. The second carries us directly to the University of Pennsylvania ENIAC.

The productive contribution to the war effort made by the mathematicians in the first World War encouraged the NRC to take a more active role in the creation of mathematical texts and, more importantly, tables. Such tables were crucial to the work of astronomers, physicists, chemists, meteorologists, and other scientists. The NRC established a committee to encourage the creation and publication of such tables and appointed to its head A. A. Bennett, who had worked under Veblen at the Aberdeen Proving Grounds. Among Bennett's most successful appointments to the committee was the British scientist L. J. Comrie, who had previously run the world's largest human computation projects and who also had direct access to an extensive literature on computing and technology.

Bennett, however, was not an effective leader, and he was replaced by one of his colleagues at Brown University, the mathematician Raymond Clare Archibald. In less than 18 months, Archibald completely reinvigorated MTAC and developed an ambitious program for developing not only new mathematical tables but also forms of computational machinery.

Making Tables

Almost all of the great moments in the early history of computing are associated with the work of what the computing pioneer and physicist, Howard Aiken, famously referred to as "making tables."

For example, in his role in the British government as an astronomer, Charles Babbage was charged with developing astronomical tables for use in the computation of longitude. His famous difference engine and its even more famous successor, the analytical engine, which is often referred to the first modern computer, were designed for the production of tables and, more specifically, to eliminate human error in the production of these tables.

In the late 1930s, at Harvard University, Aiken, working closely with the IBM Corporation, built an electro-mechanical computer known as the Harvard Mark I, or as IBM liked to call it, the IBM Automatic Sequence Controlled Computer. Aiken very explicitly looked to Babbage both for an intellectual authority and lineage but also for specific techniques. In many ways the design of those two machines is similar. The Harvard Mark I was put to work in 1937 making tables. It was so famous for its production of tables of Bessemer functions that its operators referred to it simply as Bessie.

An electronic but analog version of a difference engine, the so-called Differential Analyzer, was invented by Vannevar Bush in the late 1920s and was used to produce ballistic tables at Aberdeen. Bush, of course, would go on to be the president of MIT, the head of the Office of Scientific Research and Development during the war, and one of the founders of the National Science Foundation. He was also the visionary inventor, in the 1946 article "As We May Think," of the Memex machine. It was intended to solve the problem of the proliferation of scientific overspecialization. The machine could display all available scientific information with sharable links in the material that traced out intellectual connections. The Memex was never built, but it is seen as the progenitor of hypertext and the World Wide Web.

The table-making operations at Aberdeen would provide the direct inspiration for the ENIAC project at the Moore School of Electronics at the University of Pennsylvania. One of the first electronic programmable digital computers was, in the eye of its inventors, simply an automated form of hand calculations. Thus, the work of Raymond Archibald and MTAC, which was founded in the wake of the first World War by the NRC, leads directly to the ENIAC. In fact, 3 years before the ENIAC was first successfully demonstrated, Archibald had already established the first journal focused on computational science and technology. For the 10 years that the National Academy of Science published the journal MTAC, it was the only publication in this field. Among other things, it published in 1946 a landmark article by Herman and Adele Goldstine, "The Electronic Numerical Integrator and Computer," which was the first public presentation of the capabilities and architecture of the ENIAC.

In 1945, the Academy hosted the first public conference on electronic computing, which predates by more than 6 months the famous Moore School lectures, which are generally considered in the literature to be the first conference. In the fall of 1946, the NRC founded a second committee devoted to computing, the Committee on High-Speed Computing Devices, which included among its members central figures in the history of computing. Among its many goals, the Committee on High-Speed Computing Devices was charged with creating a new professional association that was to serve as the premier scientific and technical organization of the emerging computer sciences.

Archibald's vision for this new professional organization was foiled by two of his committee members, Samuel Caldwell and John Curtis, who voted that no action should yet be taken. Somewhat suspiciously, both Curtis and Caldwell quit the committee 6 months later and went on to form the Eastern Association for Computing Machinery, which was soon renamed the Association for Computing Machinery (ACM). The ACM did became the premier professional organization devoted to the computer sciences and remains so to this day.

A second prominent myth about the computer revolution is that nobody saw it coming. A widely repeated but apocryphal anecdote about Thomas Watson, the legendary founder and longtime chairman of the IBM Corporation, holds that he predicted as late as 1943 a total world market for maybe five computers. This myth became a cautionary parable about the dangers of relying on scientific and governmental organizations, because growth in the computer industry is so unpredictable that it is best left to individuals. Despite being untrue, the myth of the corporate and bureaucratic "dinosaur" who failed to recognize the revolutionary potential of computing is still mobilized in the popular literature. In fact, many scientists and other experts were aware of the transformative potential of computer technology, as the Committee on High-Speed Computing Devices demonstrates.

Although the potential of large-scale computing was recognized by the 1920s, no infrastructure for making that possible existed. Even when the National Science Foundation was created, it did not anticipate that computing grants would be part of its mandate. However, as early as 1953, NSF was receiving grant proposals with computing requirements. These came not just from the big science disciplines like physics and chemistry but also from the biological sciences, the environmental sciences, and increasingly the social sciences. For example, the first NSF grant was to John von Neumann for work on the significance and possibility of high-speed computing in meteorology.

Industry started to serve some of the role of providing computers to universities, but it was the publication in 1966 of an NAS report about the digital computing needs of the modern university, the so-called Rosser Report, that greatly influenced the course of investment in computing. The Rosser Report noted that the national investment in computing grew from $700 million in 1958 to $7

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billion in 1964. It called for massive growth in the federal investment of $65 million annually to a federal investment of $200 million annually. The Rosser Report was not wildly influential. It was written in a language that did not engage with policy makers, but its successor, the Pierce Report, which was produced by the NSF and built on the Rosser report, was. The Pierce Report led directly to a significant increase in investment in computing not just for physics, chemistry, and the emerging computer sciences, but also for the social sciences and eventually the humanities.

The Computer Science and Telecommunications Board

The modern organization within the NRC that guides computer science policy and development is the Computer Science and Telecommunications Board. The NAS Archives contain some wonderful material about its history. For example, a 1987 note in the archives from Joseph Traub says, "Sam Fuller says this guy Bill Gates has really thought about software. He might be a good person to talk to our board."

In 1988, the board published the report *Toward a National Research Network*. The influence of this report is undeniable. According to Michael Nelson, Al Gore "lifted" whole sections of the report in preparing the High Performance Computing Act of 1991. The act funded the National Information Infrastructure, or as Gore famously referred to it, the information superhighway. It allocated $600 million to high performance computing. It helped develop the backbone of the modern Internet. It founded a number of supercomputer centers, one of which, at the University of Illinois, produced the Mosaic web browser, which became Netscape and led to a whole set of Internet-based companies.

Many reports were issued in the 1980s and 1990s, and it is hard to assess their relevance. However, *Toward a National Research Network* illustrates some of the ways in which these reports achieve a life of their own and become tangible.

The Power of Unpredictable Consequences

Robert Kahn, *Corporation for National Research Initiatives*

I recently was at the 100th anniversary celebration of Turing's birth held at Princeton University, where Turing did his PhD work in the 1930s. Most of the other speakers were deep into logic theory, whereas I took an Internet point of view. I'm not a historian, but from what I understand, there were three distinct approaches to computing at Princeton at the time Turing was there. One was proffered by the logician Alonzo Church who was advocating an approach called lambda calculus, which later became the basis of the programming language Lisp. Another group including the mathematician Kurt Gödel was pursuing recursive function theory, which was a different approach to the mathematics of computing. Then there was Alan Turing, who was writing a thesis on computable numbers. Turing's approach may not have made much sense to people at the time, because few, if any of them, were thinking of computing as machine based. Turing proposed a model with a single read/write tape of infinite length in both directions. With his model, you could write a symbol or erase a symbol and you could move the tape left or right; Turing was able to show that, with this model, a very wide range of computations was possible. Later, it was shown that all three of these approaches were logically equivalent.

John von Neumann was not the first to point out that infinite tapes were problematical, but he proposed instead to create a finite 2D substitute in the form of a large electronic read/write memory. However, in those days, it was troublesome to accomplish even that. Some of the early electronic memories involved the use of Williams tubes, which were tiny cathode ray tubes such as used in television sets. Their screens were illuminated by phosphorescent dots to indicate what the bits were. Eventually that led to the von Neumann architecture that has thrived until now.

When people talk about the Internet, most think of it as a network; but that is not how I think about it. Creating the Internet was about enabling communication among and between many different components, whether they be networks, computers, or devices, including wired and wireless devices, and making them work together. It was about the protocols and procedures that would enable that. In addition to achieving interoperability with today's technology, these protocols make it possible to swap in and out the underlying technology as it will surely evolve over time. Network technology has changed dramatically, and computing even more since the early 1970s. However, as an architecture, the Internet has continued to function in enabling intercommunication between all of the components that constitute today's Internet.

The Unpredictable Future of Computing

In 1928, when the computing revolution had not begun, imagine that someone showed up at your front door and said, "I have these two wonderful inventions that you've never seen them before. One is a computing chip based on semiconductor technology. The other is a memory chip. Between these two you can do wonderful stuff."

Would anyone have understood the implications of that? To do so, you would have to imagine in one fell swoop all of the things that have happened in computing over many years. The notion of computing, programming language, operating systems, files—all of the things that today reflect computing were not available back then.

I could tell a similar story about ARPAnet and the Internet. Every one of these developments had its own mystery and uncertainty about future developments.

Lessons of R&D Investments

Janet Abbate, *Virginia Polytechnic Institute and State University*

One measure of the influence of Academy reports is the role they have played in providing Congress and the public with a way of thinking about science and technology. For example, a 1995 report by the Computer Science and Telecommunications Board (*Evolving the High Performance Computing and Communications Initiative to Support the Nation's Information Infrastructure*) had a particular graphic that showed the influence of government and industry funding on the development of new businesses. Besides the obvious argument, three somewhat more subtle arguments were conveyed.

First, "the payoff for research takes time." Ten to 15 years can elapse between government investments and industries that ultimately are worth billions of dollars. Research does not have a 2- or 3-year turnaround. The American people and Congress need to think of research as a more long-term enterprise.

Second, "unexpected results are often the most important." That is probably true in all of science, but it is legendary in computer science. There are many examples, such as e-mail becoming the killer app of the Internet. Again, time and slack are needed for unexpected results to percolate up and pay off.

Third, "doing research involves taking risks." Again, that is probably true in every science, but it is certainly true in computer

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science. Not everything is going to pan out, but that does not mean that funding it was a mistake. This kind of argument lays the groundwork for thinking about investments in science and technology.

In 1997, Paul R. Young, assistant director for NSF's Computer and Information Science and Engineering Directorate, was speaking at a Computer Science and Telecommunications Board symposium and referred to this figure as a powerful rhetorical tool. "It enables us to talk with policymakers and the general public about the fact that research has a long life. . .. It enables us to talk about the fact that the process is nonlinear and that the particular goals may be diffuse." Therefore, it's important, in thinking about the impact of these reports, to look at their discursive impact as well as more direct impacts on research funding or priorities.

Women in Computing

The Academy has also had an important role in producing reports about sex in science. I serve on a committee at Virginia Tech to improve the climate and the retention of women scientists, and we use these reports to guide policies at our institution.

The situation in computing is peculiar because the percentage of women in computer science rose until about the mid-1980s, peaked at around 35%, and since then has declined. The Academy's reports have tried to understand this issue. It is complex, including things like work-life balance and encouraging girls to get the background in mathematics that they need in middle school and high school so they are not disqualified from the field before they get to college. It is not a simple problem and does not have a simple solution, but people are working on it.

Observing best practices, like simply putting a woman on a hiring committee, can significantly increase the pool of women in the applications pool. It sends a subtle message that they might want to be there. Institutions that are motivated to improve their recruitment and retention can build on such practices, as can industry.

The Academy's Impact on Computer Science

David Farber, *University of Pennsylvania*

Whether computer science is a science is an interesting question. In computing, we create an artifact, a computer, and then start trying to understand how it behaves. What are the fundamental rules that govern it? What can be done with it? How does it evolve as it gets larger. That sounds like high-energy physics, which uses big artifacts to do science. However, computer science is a science of the artificial.

The Academy has had profound impacts on computer science. The Academy's support for the National Research Network helped trigger congressional action. The Academy's ability to communicate in terms that congressional members and their staffs can understand has also been an important factor. When they go to Washington, scientists often speak in terms that go right over their heads. However, if you talk down to a congressional member, you don't get far. By translating science into terms that are understandable, the Academy has had a big impact.

One interesting problem that the Academy is going to have to deal with involves the balkanization of the Internet. For a number of reasons, countries would like to have their own capabilities and minimize the information that comes into and leaves their borders. They plead privacy and other concerns, but when you dig down, you realize that it is economics, also. A lot of revenue goes out of their countries and they would prefer to keep it. No organization is yet willing to bite off that problem from a global standpoint.

Another interesting problem is the rapid change of technology. Future optical interconnections will change what can be done with networks and the devices attached to them. For many people, the Internet now sits on the end of a mobile device and not a laptop or desktop. On the other side, the physics community and other sciences want to move large amounts of data around on networks from many sites and bring the data together to analyze it. This will put strains on the network, the technology, and our understanding of how to run a network while retaining reliability, privacy, and so on. We are in for a fun time.

K-12 Science Education

As an institution composed largely of academics, the Academy has always taken an interest in science education. That interest intensified in the 1950s after the launch of Sputnik, when the federal government undertook major initiatives to improve science education and invest in educational research. In the 1970s, the Academy formed the Committee on Fundamental Research Relevant to Education, inaugurating a formal involvement in K-12 education that would intensify over the next two decades, culminating in the NRC's leadership of the national movement to develop science education standards. Meanwhile, the Academy became increasingly active in efforts to counter the challenges to science education posed by creationists.

Edward Larson, University Professor and Hugh and Hazel Darling Chair in Law at Pepperdine University, discussed the latter issue at the colloquium, tracing the history of the creationism controversy in the United States from the 1920s to the present. Michael Feuer, professor of education at George Washington University, described some of the difficulties in reforming a system as fragmented as K-12 education in the United States. David Goslin, former executive director of the NRC's Commission on Behavioral and Social Sciences and Education, listed some of the areas in which the behavioral and social sciences can contribute to educational reform. Eugenie Scott, founding executive director of the National Center for Science Education (NCSE), returned to the topic of science, evolution, and creationism and toasted the Academy's next 150 years.

The Academy and Creationism

Edward Larson, *Pepperdine University*

Polls suggest that half of all Americans reject the theory of evolution, and most of the rest believe that God guides the process. In many places, these percentages are much higher.

Given these attitudes and America's long tradition of local control over public education, the question is not why is evolution not taught more in public schools but why is it taught as much as it is? One prominent answer is the work of the National Academy of Sciences and National Research Council.

The American controversy over teaching creation and evolution can be divided into three historical phases, with an ever-

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increasing role for the Academy in each phase. The first phase of the controversy featured a national religious crusade to outlaw the teaching of the Darwinian theory of human evolution in public schools. This led to the passage of the first such statute in Tennessee and the subsequent trial of John Scopes in 1925, in which several Academy members offered their expert testimony or public commentary for the defense.

After Scopes' successful prosecution, other states and local school districts followed Tennessee in excluding Darwinism from the classroom. The Academy debated entering into the growing controversy at this point, and in 1923, it even appointed a committee, the Committee on Organic Evolution, to look into the matter. That committee prepared a statement that hailed evolution as truth and denounced its opponents for ignorance and intolerance, but the Academy ended up not releasing that statement and left the issue to politics and the courts.

The Supreme Court's landmark 1947 decision in *Everson v. Board of Education* marked the beginning of the end of this first phase of the creation-evolution legal controversy. By incorporating the first Amendment bar against religious establishment to the liberty protected by state action by the Fourteenth Amendment, *Everson* led to a series of rulings on state and local policies and practices that brought down the old anti-evolution laws.

Rise and Fall of Creation Science

With the disappearance of those laws, however, opponents of Darwinian instruction began calling for the inclusion of alternative theories of organic origins in the biological curriculum. Those calls ushered in a second phase of the anti-evolution legal controversy, which began around 1970 and reached full force by 1980. This was marked by state statutes and school board regulations mandating that, to counterbalance Darwinian instruction, schools also had to teach either the biblical account of creation or scientific evidence alleged to support that biblical account in Genesis, which goes under the term "creation science."

Now the Academy got more publicly involved. In 1972, the NAS issued a resolution condemning measures mandating the teaching of creation science in science classrooms. In 1984, it published and widely distributed an attractive glossy brochure entitled *Science and Creationism: A View from the National Academy of Science*, which distinguishes between evolution as science and creation science as religion and roundly condemns teaching creation science in the science classroom.

This booklet had the effect of stiffening the resolve of science teachers, school board members, and state legislatures who accepted the theory of evolution or opposed religion in public schools. Of course, according to the National Association of Biology Teachers, up to a quarter of American high school biology teachers reject the Darwinian theory of human evolution and want to include creationism in the classroom. An even larger percentage of school board members and state legislators accept creation science.

On these individuals, the booklet had less impact.

Under the then entrenched establishment clause principles, it did not take long for courts to end this second phase of the controversy. In 1982, after a widely publicized fact-finding trial, a federal district court declared unconstitutional an Arkansas law providing for balanced classroom treatment of creation science and evolution science. Five years later, in *Edwards v. Aguillard*, the US Supreme Court settled the matter by finding that Louisiana's Balanced Treatment Act, "advanced a religious doctrine by requiring either the banishment of the theory of evolution from public school classrooms or the presenting of a religious viewpoint that rejects evolution in its entirety." The Academy again stepped in by filing a well-written amicus brief with the court arguing that the theory of evolution was a purely and widely respected scientific theory, whereas creation science was simply religious dogma dressed up like science.

Rise of Intelligent Design Creationism

Nevertheless, many Americans remained skeptical about Darwinism and rejected the idea that it should be the only theory of origins taught in public schools. Perhaps the state could neither ban evolutionary instruction nor counterbalance it with religious or "scientific" creationism, but could state or local school districts direct that biology courses incorporate questions about the sufficiency of Darwinism in explaining natural phenomena? Also, could these questions support Intelligent Design in nature as an alternative to Darwinism? Such questions gained traction among conservative Protestants during the 1990s and spawned litigation and legislation into this new century. This launched the third phase of the creation-evolution controversy, which continues unresolved to this day.

The Academy remains fully engaged on two fronts. The first is promoting evolution teaching through state science standards. The second is opposing the so-called intelligent design agenda. With regard to the science standards, in 1988, after the seminal *A Nation At Risk* report came out, Republican presidential nominee George Bush campaigned on a platform of education reform, the first time this traditionally state and local issue dominated a national election. A highly publicized education summit was held soon after his inauguration in 1989, where Bush and the nation's governors, led by then governor Bill Clinton of Arkansas, committed themselves to the goal of having students demonstrate competency in science, mathematics, English, history, and geography by the end of the century.

Bush called the program "America 2000," and it focused the educational reform movements squarely on formulating national standards for what should be taught and learned in American public schools. In 1991, at the invitation of the National Science Teachers Association and Bush's secretary of education, the Academy assumed responsibility for drafting the standards for science education. Long a champion of rigorous instruction in evolution, the Academy, working through the NRC, now had the mandate to draft model standards for elementary and secondary science education in American public schools.

One by one during the late 1990s, the various state boards and departments of education worked through the initial standards-setting process. Most states used the NRC standards as their working draft. By 2000, every state had adopted some form of science standards that at least addressed the topic of biological evolution, although a few avoided using the word itself. Forty-six specifically included the concept of species changing over time and of natural selection; 38 included evidence for evolution; and 21 discussed descent with modification. Furthermore, what is tested tends to be taught, and most states tied student assessment testing to their education standards.

The triumph of evolution was not uniform throughout. Some states treat biological evolution very gingerly in their standards or not at all. A few insert creationist buzzwords such as "microevolution" and "macroevolution" into their standards. Three states—Kansas, Alabama, and Louisiana—are special cases and illustrate the Academy's responses to the intelligent design agenda.

State Challenges

In Kansas, the federal mandate for education standards and a gradual consolidation of state authority over education and educational policies provoked a conservative reaction.

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By 1996, Republican candidates committed to local or parental control over public schools won 5 of 10 seats on the state's elective school board. Not all of these five conservatives came from the religious right, and none campaigned on the evolution issue, but each distrusted the professional educational establishment.

In 1998, the state commissioner of education assembled a committee of Kansas science educators to draft the state's science standards. The drafting committee hued close to the NRC model. Board conservatives, however, offered a creationist alternative. Public hearings on the science standards became bitter battlegrounds between creationist parents and evolutionist educators. The drafting committee offered the compromise of just removing the word "evolution" from its proposal, but the conservatives won the day by taking over the committee's proposal and deleting offending content such as "macroevolution" and the big bang theory.

When it passed the board, a national media frenzy followed. As a practical matter, however, attention soon focused on the 2000 Republican primary, when four board conservatives would face the voters. Scores of national science organizations, including the Academy, condemned the board's actions. Indeed, as copyright holder of sections drawn from its model, the Academy blocked publication of the state's new science standards. With the nation watching, Kansas voters turned out all but one of the conservatives. The reconstructed board promptly adopted new science standards modeled on the Academy template.

Alabama took a different tack. As part of its science education standards, the state board of education declared, "Explanations of the origins of life and major groups of plants and animals, including humans, shall be treated as theory not as fact." Shortly thereafter, the board adopted a specific disclaimer for inclusion in all evolutionary biology textbooks used in public schools. This disclaimer, which is printed on the front page, depicts evolution as a controversial theory, differentiates between microevolution and macroevolution by noting that the latter "should be considered a theory," and concludes with a list of allegedly unanswered questions about biological origins. The disclaimer does not, however, expressly endorse or invoke religion.

The Academy responded to this and other intelligent design challenges to teaching evolution with a new glossy booklet, *Teaching About Evolution and the Nature of Science.* After many examples and much discussion, this booklet concludes, and again I'm quoting briefly from the conclusion, "The statements of science must invoke only natural things and processes. . .This understanding has great practical value, in part because it allows us to better predict future events that rely on natural processes. . .The theory of evolution is one of those explanations." The booklet also quotes from NAS biologist Ernst Mayr, who said "Virtually all scientists known to me have religion in the best sense of this word, but scientists do not invoke supernatural causations or divine revelation."

Alabama's textbook disclaimer has never been challenged in court and remains in effect. However, similar disclaimers that suggested or endorsed religious, intelligent design, or creationist alternatives to evolution have been struck down by the courts.

The mixed results of the disclaimer battles led critics of Darwinian instruction to seek what they call academic freedom statutes. Typically, these bills assert the rights of public school teachers and students to hold and express their own views on biological origins and other controversial science topics without identifying any specific alternative theory. They also do not single out only Darwinism for censure, which proved problematic in some bigger cases, but also question global warming, human cloning, and other "controversial theories." These bills continue to pop up in southern and midwestern state legislatures today.

Most of the proposed academic freedom bills have stalled, but in 2008, a proposed academic freedom statute found traction in the Louisiana legislature and passed. Last year, another passed in Tennessee. Expertly crafted to survive constitutional challenge in the current Supreme Court, neither statute thus far has been challenged in court.

Science, Evolution, and Creationism

After Louisiana's academic freedom act passed, the Academy responded with another glossy booklet entitled *Science, Evolution, and Creationism*, which also was designed for mass distribution. "What's wrong with teaching critical thinking or controversies with regard to evolution?" the booklet asks. It then answers, "Nothing is wrong with teaching critical thinking, but critical thinking does not mean that all criticisms are equally valid. Critical thinking has to be based on rules of reason and evidence. There is no scientific controversy about the basic facts of evolution. In this sense, the intelligent design movement's call to teach the controversy is unwarranted."

Through the science standards and publications, the Academy has advanced the cause of science education considerably. However, it has yet to checkmate its wily and determined creationist adversaries.

Changing a Fragmented Educational System

Michael Feuer, *George Washington University*

When Bruce Alberts became president of the Academy in 1993, he did so in large part because he wanted the institution to have a more prominent role in the improvement of science education, in particular at the K-12 level. Over the subsequent decade, the Academy undertook a number of activities oriented toward the ideal notion of bringing the best possible scientific inquiry to bear on problems of American education.

By law and by design, the American public school system is fragmented. The nation has something like 15,000 more or less independent school districts in 50 states and territories. These districts operate at a very local grassroots level in making decisions about content, pedagogy, and the governance of schools and schooling. That reality is the result of a system that has been evolving at least since the mid-19th century, when the first "reform" movement led to the massive expansion of the educational franchise and significant changes in school management and public accountability. The word "system," however, is perhaps a misnomer: as the former president of Harvard, James Conant, once said, "we don't actually have an education system in this country, we have a hodgepodge, and we like it that way."

The fact that "we like it that way" is one of the things that has led to tension in education reform. The controversy over teaching evolution or not teaching evolution in the schools has a lot to do with the allergy that the American people have had for two centuries to the imposition of a central authoritative position on matters of curriculum or standards.

During a meeting here at the Academy, the French minister of education, Claude Allègre, who is himself a member of the NAS, was speaking with several US education policy leaders. The minister made the point that, in France, if a decision was made on Monday to change the curriculum, then by Thursday all of the schools in the country would start doing it. Noting the envy of his audience, Minister Allègre said, "I understand that you have a certain desire for centralized control and authority. But keep in mind that in a system such as mine, where there is a great deal of decision making invested in the

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central authority, that leads to a certain amount of centralization of opposition as well." Six months later, Minister Allègre was out of a job because he had dared to suggest that French teachers devote part of their summer to professional development.

Voluntary National Testing

In his 1997 State of the Union address, President Clinton introduced the notion of something called voluntary national testing (VNT). The idea for a VNT was that in the big hodgepodge of American education, states and districts were using all kinds of tests to measure the performance of American students, and no one could get a straight answer as to how US students were actually doing. Voluntary national testing sought to bring some coherence and was hoped to promote a more common ethos about the purposes of education and the responsibilities of education authorities.

This was a very complicated undertaking. As one policy wag said at the time, there were only two things wrong with the idea of national testing: half the country hates the word "testing" and the other half hates the word "national." The VNT proposal triggered a heated debate. One question that arose, by legislators generally not comfortable with the idea of national testing, was whether results from existing state and commercial tests, in all their diversity, could be reported on a common scale, thereby obviating the need for a new program. An NRC committee was convened to look at the issue and tried very hard to figure out if that was possible. Ultimately, the committee concluded that it was not a good idea—there would be too much error in the kinds of inferences such a "linkage" technique would generate. The VNT posed other problems also. Another important NRC study, aptly called "High Stakes," highlighted the risks associated with using such a technology to make important decisions about student retention in grade, promotion, and graduation.

Finally, as has been mentioned, one of the most remarkable examples of how this institution has made a difference in the world of education policy and reform was the science standards, one of President Albert's first and most challenging projects. Development of the standards, which were summarized in several landmark volumes that helped reshape science teaching and learning at the K-12 level, also led to the creation of the Board on Science Education, which had the fitting acronym (BOSE; the board was chaired by Carl Wieman who received the Nobel Prize for his work on the Bose-Einstein theorem). Since its inception, BOSE has been responsible for continued and pioneering work on the improvement of science teaching, curriculum, assessment, and standards.

It has been a very good thing to have eminent scientists engaged in the complexities of education, despite how hard, murky, and ideologically fraught these debates are. Also, consensus has made it possible for the science of education to advance. Consensus is costly and time consuming to achieve, but it creates knowledge along the way, and no institution is as good as the Academy at pursuing consensus.

The Social and Behavioral Sciences in Education

David Goslin, *American Institutes for Research*

The social and behavioral sciences have much to contribute in addressing the most important questions in the field of education. For example, what are the capacities of learners? What are the differences among learners? What capacities do they bring to the learning process from the earliest days of their lives? How do those capacities change and accumulate over time?

What are the most effective methods to convey information from one person or one group to another? How does transfer of learning occur from one domain to the next? How important is it to learn concepts in different contexts? What are the stages of development of human beings? How do these stages interact with attempts to teach people different things? For example, children no longer have to pass a reading readiness test at the age of 5 or so before they can be taught to read.

What is it that causes learners to persist and stay on task even when they are bored or confused? Herbert Simon once said that motivation is the black hole of American psychology. American psychology has many theories of learning, but very few theories of motivation, yet the two are inextricably linked.

What is known about teaching or instructional processes? What is the most effective way to train prospective teachers to teach? The instructional system for training teachers in this country is as fragmented as the rest of the education system, with schools of education varying wildly in quality, the kinds of people they recruit, and the amount and kinds of training they receive. In most places, little attention is given to the transition from teacher training to actual practice in the classroom. This is in stark contrast to the medical profession, which requires extensive time in internship and residency programs before physicians are deemed prepared to practice independently.

How are schools structured and how are they influenced by the neighborhoods and cultures that surround them? How do we measure the output of schools? The measurement of student performance has become increasingly sophisticated, but also more controversial, particularly as proposals have proliferated to link teacher evaluations to the performance of their students on standardized tests. What is known about external influences on learning such as peers, extracurricular activities, computers, and television, all of which sometimes abet and sometimes impede learning? A large literature in the behavioral and social sciences exists on this topic.

Regarding institutional issues, how can schools be encouraged/helped to change? Policies such as the Race to the Top and other incentive-based programs apparently have had some positive effect, but the resistance of institutions to change is a well-known phenomenon in the social sciences. In the area of economics, what is known about funding for schools, including funding disparities in areas with property-based taxes as the principal means for funding schools?

In all of the foregoing areas, the social and behavioral sciences have relevant theory and knowledge to contribute to policy debates.

The Committee on Fundamental Research Relevant to Education

In 1974 when I became director of what was then the NRC's Assembly of Behavioral and Social Sciences, most of the social sciences still were relative newcomers to the membership of the Academy. Although psychologists and anthropologists had been well represented among the membership from early on, only in 1966 was the first sociologist, the demographer Kingsley Davis, elected to membership in the Academy. Political science, sociology, economics, and social psychology all were added beginning in 1966. However, when I arrived to manage the behavioral and social science division of the NRC, relatively few members of the Academy were social and behavioral scientists.

Most members of the Academy were still getting used to the fact that there were sociologists, political scientists, and economists around. However, the acceptance on the part of the Academy of all of the social and behavioral sciences has been quite remarkable over the last 35 years.

In 1976, the National Institute of Education (NIE) asked the NRC to form a Committee on Fundamental Research Relevant to

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Education to make recommendations to improve the scientific foundation of education in the United States. The director of NIE, Harold Hodgkinson, asked the committee to recommend how that strengthening might be accomplished by identifying promising lines of fundamental research.

The committee's report, which was published a year later, described eight examples of bodies of fundamental research that, in the committee's view, were of particular relevance to education. These were as follows: understanding cognitive development, brain and neurological processes, reading, education outside schools, innovation and change in educational institutions, school environments, educating children for a multicultural and multilingual society, and opportunities for higher education. The totality of the research and policy literature in the field of education over the last 35 years reflect the prescience of that first committee's insights in 1977.

The committee also spent considerable time thinking about the relationship between research relevant to education and educational practice. It concluded, remarkably for 1977, that education change is slower, more subtle, and more complex than usually envisioned and that the most important influences that fundamental research has on education come through diffusion rather than dissemination. Even then, they knew how difficult it was going to be to change our schools.

Since that first study, the social and behavioral science division of the NRC has undertaken dozens of important projects in the field of education, each underscoring the importance of these sciences for the field of education.

Defending Science at the Local Level

Eugenie Scott, *National Center for Science Education*

In 1980 and 1981, I was one of several scientists at the University of Kentucky who were opposing the introduction of creation science in the public schools of Lexington. We were joined by a strong teachers' union and the mainstream clergy, which did not want creation science to be taught Monday through Friday in the classroom and then have to straighten kids out on the weekend, because creation science was not their theology.

In 1981, I received a letter from Frank Press appointing me to an ad hoc committee on creationism. We had a 1-day meeting in October at which I spoke about the problems of organizing scientists to work on this issue. I agreed with another member of the committee, a retired high school biology teacher, Stanley Weinberg, that all politics are local. Whether and how to teach evolution is a political issue much more than it is a scientific or pedagogical issue. The solution to problems that arise over the teaching of evolution must be found locally by scientists, teachers, clergy, parents, and other interested people in individual states and communities.

Frank Press and the others agreed. If scientists were needed to testify at a school board meeting in a school, the Academy was not the institution to make that happen. It was not set up for local activism. What the Academy could do, better than any other organization, was to prepare an authoritative document that could be used by lawyers in future lawsuits and might also help educate the public and the press. Hence, the decision of the Academy was made to publish the first edition of what eventually became *Science, Evolution, and Creationism*.

The National Center for Science Education

A separate decision by a group of scientists helped form a nonprofit organization that became the National Center for Science Education. The goal of the center was to work at the grassroots level to provide citizens with the scientific information and organizing advice needed to defend science effectively in the schools.

The Academy has been a hugely valuable partner to the National Center for Science Education. It has published three versions of the *Science and Creationism* booklets. It created an extremely helpful website for teachers and the public. When the National Center for Science Education needed an amicus brief signed by scientific associations for *Selman v. Cobb County*, the Georgia case focused on textbook disclaimers, we went first to the Academy because we knew that if the Academy signed on, then the associations would follow. Overall, 56 scientific societies and educational associations signed that amicus brief, which the judge cited in his decision.

On many occasions, Bruce Alberts and Ralph Cicerone have had op-eds published in regional newspapers where there have been controversies over the teaching of evolution. Even more valuable has been the Academy asking its members in a particular state to speak up when evolution is under attack—to themselves write op-eds or testify at board of education or legislative committee meetings. All politics is local, and local scientists have much more clout than do national ones.

Behind the scenes, NCSE staff have helped the Academy's staff answer letters from the public about obscure points like why polonium halos prove the Earth is only 6,000 years old or why polystrate trees prove Noah's flood. The Academy staff should not be wasting their valuable time figuring out these arcane contentions. That's why we exist.

The 1994 National Science Education Standards, largely because of the smart way in which the Academy conducted the writing, critique, and consensus analysis, had considerable influence on science education standards prepared by the states during the 1990s and 2000s. By bringing in educational leaders from around the country, the Academy ensured that states were more likely to implement its approach when designing their own standards. Today, the next-generation science standards, which focus on the integration of inquiry learning with the content of science, could significantly change the teaching of science in the United States and significantly improve public science literacy.

I would like to thank the Academy for its help and leadership in science not only on the controversial issues of evolution and climate change but across science, technology, engineering, and mathematics education. Here's to another 150 years.

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