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How Science Became Technical

By Theodore M. Porter*

ABSTRACT

Not until the twentieth century did science come to be regarded as fundamentally technical in nature. A *technical* field, after all, meant not just a difficult one, but one relying on concepts and vocabulary that matter only to specialists. The alternative, to identify science with an ideal of public reason, attained its peak of influence in the late nineteenth century. While the scale and applicability of science advanced enormously after 1900, scientists have more and more preferred the detached objectivity of service to bureaucratic experts over the cultivation of an engaged public. This reshaping of science, which has been both celebrated and condemned, provided a stimulus to the incipient field of history of science, and it remains a key historical problem.

IN A FAMOUS EPISODE during the investigation of his security clearance in 1954, J. Robert Oppenheimer was asked to explain his change of view on the development of a hydrogen bomb. He replied that the design, as reconstructed, was so "technically sweet" that, for a physicist, it had become compelling. It is an odd rationale for a weapon that was to recast international power relations and would have the capacity to kill billions of innocent people. Oppenheimer, though famous for his cultural sophistication and commitment to the interdependence of science and the humanities, seems to have chosen this language as a politically acceptable rationale for a scientist's stance on a question of high politics and national security.[1] Certainly his inquisitors discouraged him from speaking to

* Department of History, UCLA, 6265 Bunche Hall, Box 951473, Los Angeles, California 90095-1473.

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[1] See Charles Thorpe, *Oppenheimer: The Tragic Intellect* (Chicago: Univ. Chicago Press, 2006), pp. 223–224. See also Kai Bird and Martin J. Sherwin, *American Prometheus: The Triumph and Tragedy of J. Robert*

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issues that went beyond science, which they regarded as none of his business. This confinement of the scientist, *qua* scientist, to the domain of technicality is one of the signal developments in the modern cultural history of science. There was, of course, nothing new in the understanding that much science is difficult and that special skill or knowledge is commonly required to carry out the work. Yet for most of its history inaccessibility was taken neither as fundamental to science nor as desirable. Right up to the 1920s and 1930s, the most prominent advocates of science emphasized instead its contribution to a moral, economic, and intellectual order, sometimes as reinforcing tradition but often, and more consequentially, as a challenge to ancient authorities or established religion and a promising foundation for moral as well as intellectual progress. That ideal of science, as an essential part of public life, was not extinguished in the twentieth century, yet the vast modern expansion of scientific institutions and resources was accompanied by a sustained effort—simultaneously irresistible and impossible—to confine science to matters technical. It was, in effect, a withdrawal of the preeminent institution of rational inquiry from the drive for public reason.[2]

What does it mean to identify science with the technical? The Greek word "*techné*," according to Aristotle, pertains to practical knowledge, as in medicine or cooking, which cannot be generalized. The English "technical" did not, until late in the nineteenth century, refer specifically to technology, but more often to the argot of a trade or to knowledge that is confined to a particular profession. "In a science like law," wrote Sydney Smith, one of the founders of the *Edinburgh Review*, in 1809, "there must be technical phrases, known only to professional men." Smith described these legal technicalities as necessary but unthreatening: "Business could not be carried on without them: and what avail would it be to repeat such phrases to the people?"[3] And yet, we know, ostensibly technical considerations can have serious consequences in the form of lawsuits and bankruptcies and home foreclosures. In science, as well, technical points can have far-reaching consequences and inspire passionate controversy. Yet the application of the term "technical" encourages us to shunt these issues off for consideration by specialists. The United States government invokes technicality to refer to knowledge outside the public domain, implying that little harm is done in censoring specialized science by assigning a security classification.[4] Democratic moralists have inveighed against the pretensions of experts for more than a century. The converse problem has been less noticed, though it is even more consequential: that what is not mainly technical is often understood as outside the proper domain of science and therefore as not amenable to empirical inquiry or reasoned argument.

The special association of "technicality" with science is quite recent, dating from around the beginning of the twentieth century. Even then, phrases like "technical science" and "technical mathematics" applied mainly to engineering fields. By 1900, expert knowledge of the materials and processes of industry had become the very model of

Oppenheimer (New York: Knopf, 2005), p. 377; and David C. Cassidy, *J. Robert Oppenheimer and the American Century* (New York: Pi, 2005), pp. 249–250, 263, 345–347.

[2] Theodore M. Porter, "Speaking Precision to Power: The Modern Political Role of Social Science," *Social Research*, 2006, *73*:1273–1294; and Thomas Bender, "The Erosion of Public Culture: Cities, Discourses, and Professional Disciplines," in *The Authority of Experts*, ed. Thomas Haskell (Bloomington: Indiana Univ. Press, 1984), pp. 84–106. More generally, see Bender's fine collection of essays, *Intellect and Public Life* (Baltimore: Johns Hopkins Univ. Press, 1993).

[3] Sydney Smith, "Characters of the Late Charles Fox," *Edinburgh Review*, July 1809, *14*(28):353–360, on p. 359.

[4] Robert B. Laughlin, *The Crime of Reason and the Closing of the Scientific Mind* (New York: Basic, 2008).

technicality. Its results were clearly important, yet few felt any need to peer inside this black box. The reason involves trust, but probably not trust in the good moral character of the specialists so much as an expectation that the rules are precise enough, that the issues are—well—technical, and that the demands of the job leave little opportunity for waywardness. And yet spokesmen for engineering were loath to define their field as set apart from issues of moral, political, or cultural significance. Typical is the peroration of Robert Thurston, mechanical engineer and pioneer of scientific instructional laboratories, at the opening of Engineering Hall at Iowa State College on 22 May 1903. Thurston insisted there on the bonds joining technical education to "scientific method," on the one hand, and to "general education and 'culture,'" on the other. "The mission of science, therefore, in the broadest sense, is the promotion of all human knowledge and, through the extension of learning and culture, to give wisdom and to offer opportunity for its exercise. Its direct product is material advance in the industrial system."[5] Thurston wanted technological understanding to be recognized as valuable for everyone, as something that cannot be walled off from general knowledge.

The opposite ambition—to keep outsiders ignorant—was in accord with a long craft tradition that did not regret, but cherished, the secrets by which skilled practitioners were enabled to preserve the trade for members of the guild. The ancient professions of law and medicine, though drawing on formal knowledge, guarded their monopolies and enhanced their economic positions with this kind of technicality. Engineering, with its ties to industry, was more ambivalent about secrecy, and the move of practical knowledge toward universities and *science* signified in general a validation of openness. Yet science itself presented two faces to the public. Although its disposition to codify and to publish worked against secrecy, the reliance on highly specialized language and methods tended to make it inaccessible. So something serious was at stake when "pure" or "basic" science began to be described as technical. The appropriateness of that term did not depend on links to economically important technologies but pointed to the arduous training required to master science, its reliance on special tools and instruments in mostly inaccessible sites, and its inscription in unfamiliar terms and symbols. For centuries, science had been supposed to partake of more exalted values of truth and humility before nature, which could not be consigned to the domain of mere instrumentality. By 1900, the ever more powerful tools of scientific investigation seemed to be turning back and undermining one of the main impulses behind such study: to expand human understanding and to light up the darkness with knowledge. The advancement of knowledge in countless recondite domains surely meant progress, but was the price too high? In 1914, for example, an American mathematician applauded the "higher, technical mathematical field" and in the next breath lamented its fragmentation into many little domains, each known only to specialists.[6]

It is no accident that the organized study of history of science grew up along with this rising sense of scientific technicality. The relationship of our field to technical science can only be called paradoxical. In 1919, as the American Association for the Advancement of Science was contemplating the creation of a historical section, a commentary in *Science* noted that the sort of history that would be most interesting to mathematicians would require "considerable technical knowledge" that could scarcely be comprehended by

[5] Robert H. Thurston, "Functions of Technical Education for Business and the Profession," *Science*, 19 June 1903, *17*:961–975, on pp. 962–963.

[6] H. E. Slought, "Retrospect and Prospect," *American Mathematical Monthly*, Jan. 1914, *21*:1–3.

others. And in general: "If such a section is formed it should be understood that the more technical and perhaps the more important part of science is of such a nature that it can be appreciated only by specialists in the fields to which it relates."[7] Thus did the most irredeemably abstruse aspects of science come to seem particularly deserving of respect. Why should there be, among historians, specialists on science at all? The answer was always that its technical content required special knowledge on the part of those who would research its past. At the same time, it has been a mission of history to help make these technical specialties intelligible to one another and, still more, to bridge the gulf between science and culture or science and the public. And yet some prominent advocates for science now regard it as very strange, and perhaps dangerously relativist, if historians seem to imply that the technical content of science is in any way secondary to something else.

The field of history of science has, in any case, been uncertain about where to locate the technical heart of science. The founding generation of the early postwar period, for which we might use the name of Alexandre Koyré, regarded science as branching off from philosophy and looked to the ancient Greeks for its origins. Educated Europeans have long been accustomed to associating the sources of rationality and science with the Greek spirit. Historians of scientific ideas assigned special significance to logic and mathematics, to demonstrations independent of time and place that provided a model of public reason. Edgar Zilsel's sociological, Marxist-tending alternative put more stress on experimental work and looked particularly to craftsmen as pioneers of science. Zilsel did not reduce science to the skill of artisans but regarded them as a necessary complement to the more intellectual tradition. His social history emphasized the economic processes that brought them into association with scholars and philosophers. Experiment might also be understood as a mode of rational demonstration, but Zilsel's analysis brought out a different sense of technicality, of highly developed craft rather than mathematical rigor.[8]

This distinction is often understood in terms of subject matter, a contrast between temperamental laboratory instruments and the mathematician's sharpened pencil, but our most acute scholars have long known better. Thomas Kuhn identified the origins of modern science with the classical, mathematical tradition while recognizing normal science as craftlike in its day-to-day conduct. Michael Polanyi's tacit knowledge took in mathematics no less than experimentation and supported a vision of science as something very hard to plan or regulate, because its essence was to be found in the intensely personal relationships of specialist colleagues and, especially, of teachers and students.[9] Oppenheimer also sometimes talked of science as a refined set of technical skills that was passed along in a very personal way from master to pupil.[10] He especially emphasized this aspect of science when he was most threatened by the McCarthyite inquisition. Highly technical knowledge, in this sense, resists meddling by outsiders.

[7] G. A. Miller, "Discussion and Correspondence Apropos of the Proposed Historical Section," *Science*, 9 May 1919, *49*:447–448.

[8] Alexandre Koyré, *Études Galiléenes* (Paris: Alcan, 1940); Koyré, *Metaphysics and Measurement: Essays in Scientific Revolution* (Cambridge, Mass.: Harvard Univ. Press, 1968); and Edgar Zilsel, "The Sociological Roots of Science," *American Journal of Sociology*, 1942, *47*:544–562.

[9] Thomas S. Kuhn, "Mathematical versus Experimental Traditions in the Development of Physical Science," *Journal of Interdisciplinary History*, 1976, *7*:1–31, rpt. in Kuhn, *The Essential Tension* (Chicago: Univ. Chicago Press, 1977); and Michael Polanyi, *Personal Knowledge: Towards a Post-Critical Philosophy* (Chicago: Univ. Chicago Press, 1974). On craft and locality in mathematics see Andrew Warwick, *Masters of Theory: Cambridge and the Rise of Mathematical Physics* (Chicago: Univ. Chicago Press, 2003).

[10] Thorpe, *Oppenheimer* (cit. n. 1), pp. 255–259.

That should give us a hint about its significance. The view of science as unarticulated and indeed ineffable skill is science circling its wagons to ward off incursions from politics and religion. It is the most profound internalism of all. It also tends to limit the scope of scientific claims. Steven Shapin argues convincingly that science is a skill anchored in specialist communities. We trust scientists, he suggests, for the same reason we trust the mechanics who repair our cars: not on account of their superior rationality, but because they have the skills and expertise to do this work, while we do not.[11] But even if we should all have such good fortune in auto repair, what can we trust these specialists to do? We would not put too much stock in the opinion of our mechanic that, since a car in good working order can easily drive right across national boundaries, there is no alternative for the European Union but to ratify a unified constitution and for other continents to follow the same model. The technical specialist, like the mechanic, knows how to do a particular job—and apart from that has opinions like everyone else.

How could things be otherwise? Well, we might take seriously the idea of "scientific method." Those who think science is at bottom a set of particularized crafts could scarcely put much stock in any general method of science, and the philosophical historians of science like Koyré and Kuhn were not impressed by it either. In twentieth-century America, it lodged itself in educational writings, a codified, simplified, exposition of John Dewey for a curriculum that valued "life adjustment" over the mere transmission of knowledge. Dewey and his admirers, seeking to expand the scope of practical rationality, declared that the decisions of everyday life should be made according to a deliberate, unbiased method. The university scientists who took the lead in Cold War efforts to upgrade physics teaching were outspoken in their disdain for textbook notions of scientific method. They interpreted science as a highly demanding craft that could be mastered only with years of study and practice. At the same time, however, they did not construe science as a thing apart but, rather, as a part of "our"—that is, European—culture and as a key element in the "humanistic foundations of Western civilization." Here again, the field of history of science played a role in the story, since these educational reforms were crucial for the establishment of history of science in American universities. James B. Conant's "Natural Science 4" at Harvard was the fulfillment of a wish to raise the scientific enterprise above the merely technical by putting it at the heart of an elite education. And the more serious versions of scientific method, like Dewey's, were broadly allied to this effort. They emphasized moral attitudes such as disciplined curiosity and respect for empirical facts rather than reducing discovery to a five-step procedure that you too can follow on your own. Postwar philosophers and social scientists, such as Karl Popper and Robert K. Merton, construed the critical, evidence-based methods of science as integral to Western democracy and as what the German Nazis and Soviet Communists most conspicuously lacked.[12]

My own interest in the topic of this lecture was stimulated by my effort to make sense

[11] Steven Shapin, "Why the Public Ought to Understand Science-in-the-Making," *Public Understanding of Science*, 1992, *1*:27–30, on p. 29; and Shapin, *The Social History of Truth: Civility and Science in Seventeenth-Century England* (Chicago: Univ. Chicago Press, 1994). This argument also harmonizes well with recent efforts to close up the space between science and technology; see Shapin, *The Scientific Life: A Moral History of a Late Modern Vocation* (Chicago: Univ. Chicago Press, 2008).

[12] John L. Rudolph, *Scientists in the Classroom: The Cold War Reconstruction of American Science Education* (New York: Palgrave, 2002), p. 119; and David Hollinger, *Science, Jews, and Secular Culture* (Princeton, N.J.: Princeton Univ. Press, 1996). On science in Western civilization as understood by early professional history of science in the United States see Charles C. Gillispie, *The Edge of Objectivity* (Princeton, N.J.: Princeton Univ. Press, 1960).

of Karl Pearson, founder of the modern field of statistics, whose unwieldy career and far-flung ambitions elude all our generalizations. Pearson, a late Victorian who survived into the era of fascism, was a great admirer of medieval guildlike universities. He believed sufficiently in science as craft that he rejected textbooks and refused to write any, preferring to offer statistical instruction face-to-face in his biometric laboratory. Yet he taught that scientific method was universal and that impersonal science was the only acceptable way to reach consensus and to provide a basis for citizenship in a modern society. Pearson built his reputation in a highly technical field, one he applied aggressively to almost every kind of social or scientific problem. He made enemies by denouncing the scientific ignorance of doctors, economists, and psychologists who failed to appreciate the power of quantitative analysis or abused it because they lacked the appropriate mathematical expertise. And yet his vision of statistics was allied to a powerful sense of public reason, a campaign to put science in the place of dead languages as the basis for education and as the successor to Christianity as the moral foundation of the coming socialist state.[13]

Pearson's program for statistics, extended and reshaped by his successors, was one of the great scientific success stories of the twentieth century. But his moral/historical ideals are now almost unthinkable. Social and historical studies of science since the 1930s have helped to bury them by relegating statistics—along with exalted forms of exactitude such as mathematics as well as more humble ones such as accounting, cost-benefit analysis, metrology, interchangeable parts, and the development of standards—to the domain of technical specialists. In recent decades, a generation of scholarship by some of my most brilliant colleagues, including Ian Hacking, Lorraine Daston, Norton Wise, Mary Morgan, Donald MacKenzie, and Alain Desrosières, has shown with wonderful particularity how the quantitative things we usually think of as technical are bound up with philosophy, labor practices, markets, imperialism, public investment, social administration, insurance, poverty, transport, medical therapeutics, nationalism, imperialism, criminal law, electrification, art, and objectivity.[14] But there are, I think, implications that we have not yet realized. It is time to put the category of the technical into historical perspective.

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For historians, the question of how science became technical presupposes the consideration of when. One answer comes back immediately: from its very origins, and by its very nature. Indeed, there was technicality in science from the time of the ancients. At first blush we may think the technical is most perfectly exemplified in mathematics, and this would not be false. But Plato was not alone in thinking mathematics a prerequisite to philosophy, and in the European tradition it has been second only to ancient languages and

[13] Theodore M. Porter, *Karl Pearson: The Scientific Life in a Statistical Age* (Princeton, N.J.: Princeton Univ. Press, 2004); and Porter, "Is the Life of the Scientist a Scientific Unit?" *Isis*, 2006, *97*:314–321.

[14] E.g., Ian Hacking, *The Taming of Chance* (Cambridge: Cambridge Univ. Press, 1990); Lorraine Daston, *Classical Probability in the Enlightenment* (Princeton, N.J.: Princeton Univ. Press, 1988); M. Norton Wise, "Work and Waste: Political Economy and Natural Philosophy in Nineteenth-Century Britain," *History of Science*, 1989, *27*:263–317, 391–449, 1990, *28*:221–261; Mary Morgan, *The History of Econometric Ideas* (Cambridge: Cambridge Univ. Press, 1990); Donald MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets* (Cambridge, Mass.: MIT Press, 2006); Alain Desrosières, *La politique des grands nombres: Histoire de la raison statistique* (Paris: La Découverte, 1993); Lorenz Krüger *et al.*, *The Probabilistic Revolution*, 2 vols. (Cambridge, Mass.: MIT Press, 1989); Gerd Gigerenzer *et al.*, *The Empire of Chance: How Probability Changed Science and Everyday Life* (Cambridge: Cambridge Univ. Press, 1989); and Theodore M. Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton, N.J.: Princeton Univ. Press, 1995).

literature as the basis of elite education. If we define the technical not just as what is difficult, but as what is inaccessible and, by general consent, dispensable for those with no practical need of it, then technicality may be less closely associated with an ideal of rigorous demonstration than with craft techniques and recipes. One great ambition of science since the eighteenth century has been to open up the private world of skill and guild secrecy by articulating, rationalizing, and systematizing technological processes. Still, mathematical inaccessibility runs through the whole history of science, and if Locke could ask Huygens to confirm the correctness of Newton's derivations so that he could proceed philosophically without having to learn the mathematics, that must count as a persuasive indicator of technicality.

While technical knowledge along the lines of Newton was expanding in every direction by 1700, there is also a sense in which science was becoming less technical. That is because it began to seem more important that every educated person should understand science. Voltaire, who made it his career to light up the world with knowledge, derived no pleasure from mathematics, but he made a modest effort, and he worked quite seriously with his lover Madame Du Châtelet on experimental natural history. Science was unmistakably linked to the campaign for enlightenment, and the idea that science should be practical, accessible, and morally uplifting inspired sharp criticism of its more mathematical incarnations by *philosophes* such as Diderot and Buffon.[15]

Even mathematics, however, was sometimes enlisted as vital to the campaign to advance justice and morals. We might have expected Condorcet, never the most elegant of mathematicians, to favor science as a mode of technical reasoning. And in a way he did. His mathematical theory of elections and judicial decisions was directed mainly to the Crown, which in practice meant elite functionaries. That nexus of science and administration, which took shape in the eighteenth century, has endured as a key aspect of the public role of science. In this form, science has been brought to bear on important matters of state and of policy without being communicated to the public. By Condorcet's time, technical science of an industrial sort was becoming especially important in the academies, schools, and bureaucracies of absolute monarchs who often owned mines, supported navies, and provided the capital for manufacturers. Of course, the savants hoped also to enlighten their rulers. However, while Frederick II of Prussia and Catherine of Russia (each of whom knew a few things about how to be remembered as "Great") might seduce Voltaire or Diderot with a professed interest in mixed government or the rights of the people, they consulted their savants mainly for advice of a specialized kind. How glorious could they be if their mines were flooded and their fountains only burbled? The French state relied increasingly on technical knowledge in the last years of the Old Regime and then a great deal more during the crises of the Revolution and Napoleon's wars. Laplace, who took a leading role in efforts to tally the French population, and Lavoisier, who applied his chemical knowledge to munitions and his financial experience to the project for a national accounting, are exemplary figures from this standpoint. Charles Gillispie, Eric Brian, and Ken Alder have rewritten the history of France in the late eighteenth century to take account of these activities. Their work is about science, not merely as a project to advance institutions of basic research, but in its role as public servant, allied to social as well as industrial and agricultural technologies.[16]

[15] Gillispie, *Edge of Objectivity* (cit. n. 12), Ch. 5.

[16] Charles Coulston Gillispie, *Science and Polity in France at the End of the Old Regime* (Princeton, N.J.: Princeton Univ. Press, 1980); Gillispie, *Science and Polity in France: The Revolutionary and Napoleonic Years*

And yet, these technical services were, in the eyes of practitioners, only one element of the public value of science. The social acceptance of science in the eighteenth century depended on the cultivation of a larger, elite audience. Genteel audiences evinced enthusiasm even for mathematics—satirists made much of the early eighteenth-century mathematical rage among fashionable women—and most notably for experimental demonstrations of balls arcing through hoops, birds suffocating under air pumps, and electrically charged orphans discharging great sparks while suspended from silk strings. All of this sounds frivolous, and maybe it was, but serious careers, including the career of science itself, were sustained by such performances. By the end of the century, science was increasingly taking account of, and sometimes addressing, larger audiences.[17]

Condorcet was not interested in scientific entertainment for the fashionable. Neither did he focus on practical teaching in mensuration and instruments for skilled workers, as did many scientific lecturers in industrializing Britain. His social mathematics was obscure even to mathematicians. Yet the great ambition of his last years was to reorient the educational system around science. Technological instruction he thought suitable to prepare people to earn a living, while mathematics and science, including social science, had also a more exalted role. They were suited to instill "general culture" and to form citizens and elites. This "culture," to be sure, was not literary and intuitive but explicit and systematic. He supposed that it could almost be mechanized, and in that sense it bordered on the technical. Condorcet did not yet partake of the typical nineteenth-century faith in science as the more formal element in a bourgeois or aristocratic wisdom that harmonized the faculty of reason with a privileged upbringing and experience of political affairs. For the mathematician Condorcet, as for much social science in the twentieth century, true knowledge had to be imported from outside the social system (that's where he located science), forming minds by training people to reason and to analyze their ideas. Yet it could be diffused to the population, he believed. "Experience also proves that in all countries where the physical sciences have been cultivated, barbarism in the moral sciences has been more or less dissipated and at least error and prejudice have disappeared." Science, he went on, can free men and women from passion and superstition, "those great prejudices that have seduced nations," which are founded as a rule on false doctrine concerning nature. The moral sciences—what he later called social science—should learn from the physical sciences to emphasize observation of facts and their communication in an exact language. Precision and proof, after all, can bind men to reason, thereby enabling them to earn the status of free citizens. And against those radicals who argued that the republic needed virtue, not science, Condorcet interpreted science as the proper *foundation* of virtue, which was intellectual as well as moral.[18]

Condorcet mainly addressed himself, as had so many *philosophes*, to savants and social elites, but in this age of revolution he began to think it necessary to enlighten the public. And this inspires me to correct a little error in the naming of modern historical periods. The Enlightenment—if this term may be taken to designate a faith in progress through the

(Princeton, N.J.: Princeton Univ. Press, 2004); Eric Brian, *La mesure de l'État: Administrateurs et géomètres au XVIIIe siècle* (Paris: Michel, 1994); and Ken Alder, *Engineering the Revolution: Arms and Enlightenment in France, 1763–1815* (Princeton, N.J.: Princeton Univ. Press, 1997).

[17] Mary Terrall, *The Man Who Flattened the Earth: Maupertuis and the Sciences in the Enlightenment* (Chicago: Univ. Chicago Press, 2002); Simon Schaffer, "Natural Philosophy and Public Spectacle in the Eighteenth Century," *Hist. Sci.*, 1983, *21*:1–43; and Geoffrey Sutton, *Science for a Polite Society: Gender, Culture, and the Demonstration of Enlightenment* (Boulder, Colo.: Westview, 1995).

[18] Keith Baker, *Condorcet: From Natural Philosophy to Social Mathematics* (Chicago: Univ. Chicago Press, 1975), pp. 75, 124, 230, 290, 297.

popular diffusion of knowledge—took place in the *nineteenth* century. Eighteenth-century *philosophes*, right up to Condorcet, looked to make the world better by appealing to kings and ministers. But in the new era of democratic and industrial revolutions, champions of science began to act as if it mattered that their results and their mode of thought be communicated to the general population. This shift was first visible in America and Britain, and by 1789 it was becoming widespread in Europe. In the nineteenth century, the Republic of Letters gave way to a more public culture of science. That also is when social science was born, not as a set of research specialties but as a campaign to raise the general level of social understanding and to help states adapt to the new world of political ideology and industrial transformation.[19]

Other, more specialized, forms of science went on as well in the nineteenth century—and indeed flourished as never before. The expectation that science should serve the state, especially in wartime, was a powerful force for the expansion of technical knowledge, as was the interpenetration of science and industry in an emerging technological age. The increasing scale of science permitted and in a sense required sharper distinctions among different subjects of research, a proliferation of disciplines. Nineteenth-century savants were painfully conscious of growing specialization and a consequent loss of comprehensibility, even within science. Philosophically inclined scientific authors tried to hold the field of science together and to clear the way for its expansion to topics involving life, mind, and society by articulating the methods of scientific inquiry. Even as the sciences were being subdivided according to subject matter, such inquiries helped to create *science* as a single cultural category, encompassing what before had been manifested in such heterogeneous forms as natural philosophy, natural history, mixed mathematics, and experimental physics. But how should science address its public, and what exactly did it have to contribute to intellectual progress and enlightenment when so much was knowable only to a select few? The twin problems of specialization and technical inaccessibility became serious concerns in the nineteenth century.[20]

Claude Henri Saint-Simon and his renegade disciple Auguste Comte have often been credited with the invention of scientism or of technocracy. But they did not celebrate specialized expertise. In truth, both grew discouraged by the failure of contemporary savants to live up to their ideal of a more unified science that would be meaningful to the public. Comte, who had had an excellent scientific training at the Ecole Polytechnique, complained even as a student of the typical narrowness of mathematical instruction. His program for mathematics displayed in microcosm an emerging commitment to the integration and renovation of society. Two or three centuries earlier, he declared, at the time of the Reformation, it had been the mission of positive science to critique the old theological order. Mathematics had then been at the forefront, and, as the avant-garde of positive philosophy, it pointed the way to the future. That was the moment of glory for this science of maximal abstraction. But in 1820 or 1840, as the need to reconstruct society was growing ever more urgent, the ideas of mathematics were becoming more fragmented

[19] This point has been widely recognized by historians for a long time, and I think it best to avoid making it depend on the special claims for a bourgeois public sphere, as developed in Jürgen Habermas, *The Structural Transformation of the Public Sphere: An Inquiry into a Category of Bourgeois Society*, trans. Thomas Burger (Cambridge, Mass.: MIT Press, 1989).

[20] Theodore M. Porter and Dorothy Ross, "Introduction: Writing the History of Social Science," in *The Cambridge History of Science*, Vol. 7: *Modern Social Sciences*, ed. Porter and Ross (Cambridge: Cambridge Univ. Press, 2003), pp. 1–10; and Porter, "The Social Sciences," in *From Natural Philosophy to the Sciences*, ed. David Cahan (Chicago: Univ. Chicago Press, 2003), pp. 254–290.

and dispersed than ever before. Mathematicians, working contentedly in their tiny areas of research, now stood in the way of the needed reconstruction.[21]

Comte condemned them bitterly. To be sure, he had his allies within French science. A few, including Joseph Fourier, François Arago, Alexander von Humboldt, and the biologist Henri Blainville, were interested enough to attend the initial series of lectures for the *Cours de philosophie positive* and later found themselves adored as saints in Comte's religion of humanity, with a day or a month named after them in the positivist calendar. But others remained mired in their specialties, and that, Comte knew, was not the way of the future. Lesson 56, in the sixth and last volume of Comte's *Cours*, addresses the *age de la specialité*, which, by the logic of historical evolution, should be giving way, as indicated in Lesson 57, to the *age de la géneralité*. But, alas, certain savants were standing in the way of this bridge to a bright future. Comte interrupts his explanation of the great social and intellectual forces of postrevolutionary France to deal with their recalcitrance. Unfortunately, as he could see, much of it was anchored in personal hostility to himself. For example, the Académie had refused to recommend him for a chair at the Ecole Polytechnique. "I would have liked," he said, "to be able to suppress or to mollify this painful examination, were it not so clearly necessary to the final purposes of my account."[22] But this duty could not be shirked, for his personal experience embodied in microcosm the sad neglect by his contemporary savants of those ideas and morals that should lead civilization into the promised land. Reluctantly, he set out to explain how his colleagues had mistreated him—not out of pique, but because it showed what had gone wrong with science.

And what had gone wrong? The scientific class was refusing to step up and assume the burden of its historic mission. History shows, Comte explained, that the greatest political obstacle to the elevation of a class is almost always blind resistance from *within* that class. Just now, that resistance was arising mainly from the mathematicians, who had once been in the forefront of positivity but who could not admit the urgent need for new sciences and a new philosophy. They treated specialization as a requirement of their vocation and refused to recognize that what he called the "dispersive regime," far from safeguarding science, undermines it. Analysis had fashioned the stones for the great edifice, but, alas, the masons would not suffer the architect. Comte had the courage to name names. The charlatanism of Laplace had been elevated over the genius of Lagrange. Thenard, Brongniart, Poncelet, and Poinsot, insisting on the continued supremacy of an inappropriate mathematics, had even blocked Comte's appointment to a professorship. These men were driven by self-interest and confined by a narrow vision. Comte himself came now to perceive that the role of savant (we might say "scientist") was becoming superfluous. The work of science should be divided between the labor of technicians, who could be as narrow and specialized as they chose, and the capacious thinking of philosophers, absolutely necessary for the healthy development of society.

Comte's characterization of the technician combines our two main senses of the term, the narrowly professional and the technological. He believed in technical knowledge, but only as a workaday thing. If most savants lacked the necessary amplitude and elevation

[21] Auguste Comte, "Plan of the Scientific Operations Necessary for Reorganizing Society" (1822), in *Auguste Comte: The Essential Writings*, ed. Gertrude Lenzer (Chicago: Univ. Chicago Press, 1975), pp. 9–67, on p. 25; and Mary Pickering, *Auguste Comte: An Intellectual Biography*, Vol. 1 (Cambridge: Cambridge Univ. Press, 1993), p. 161.

[22] Auguste Comte, *Cours de philosophie positive*, 6 vols. (1828–1840), 2nd ed., Vol. 6 (Paris: J. B. Baillère, 1864), Leçon 57, p. 375.

of real thought, then let them be engineers and labor merely to direct the action of man on the external world. A select few were rising above science and becoming philosophers, pursuing the moral and spiritual regeneration of society. These saints of humanity were blocked by the narrow technician-savants. Sometimes it gets personal, as our brave author knew all too well. Yet the time was ripe for those of enlarged vision to create a real intellectual government based on positivity. This would be led by the new "social science," following along a path that had been cleared by biology. These sciences of life and society, the culmination of human intellectual development, had to engage with concrete complexity and could not succumb to the narrowness of mathematics.[23]

Oddly, Comte's fulminations against mathematics during the 1830s coincided with an efflorescence of public science in France. This was, after all, the nineteenth century, when science was enlisted in a civilizing mission. To the new popularizers, the dark continents of urban poverty and factory labor required enlightening just as much as the colonies in Asia and Africa. Popular science had a central place in this great project. One reason for scientific education was specifically practical and, we may say, technical: to improve the skills of workers, artisans, and engineers. Another was moral uplift: to give working people something dignified to occupy their attention. Sometimes, personal improvement was offered as an alternative to class resentment and organization into trade unions or socialist political parties. But Marxian and other socialists also claimed the mantle of science, and so its political implications became uncertain and contested. The history of science in the nineteenth century is a story of rival visions and of efforts on the part of gentlemanly practitioners to secure orthodoxy in the name of scientific competence. Phrenology, theories of evolution, and socialist political economy all became targets of elite science, which condemned them as false and dangerous. Historians in our own day have brought a full measure of disdain to bear on the Society for the Diffusion of Useful Knowledge and its ilk for seeking to distract workers from their legitimate discontent by preaching science, usually in alliance with Christianity. We might prefer to be more evenhanded. Gentlemen and workers alike valued the technological side of science—and also saw science as dense with moral significance. The engagement of workers and scientific elites was not a battle of unflagging antagonists but a patchwork of shifting alliances and ambivalences as well as conflict. The scientific establishment, far from hegemonic, faced skepticism and rival visions from bishops and dukes above as well as from journalists, mechanics, and working-class naturalists below. Nobody thought that the issues surrounding science were merely technical.[24]

While the relations of science and Christianity had been intermittently tense since the Middle Ages, they were often seen as mutually supporting—and perhaps never more so than in the early nineteenth century. Late-century naturalism, by contrast, presumed that the civilizing mission of science could be exercised independently of institutionalized religion, perhaps even in opposition to it. In Britain and America, evolution, energy conservation, and statistics posed a challenge to Christian doctrines of providential design as well as human free will and divine intercession as a response to prayer. In Germany and

[23] *Ibid.*, pp. 379, 390–395.

[24] The scholarship on these issues is particularly rich for nineteenth-century Britain. See, e.g., Roger Cooter, *The Cultural Meaning of Popular Science: Phrenology and the Organisation of Consent in Nineteenth-Century Britain* (Cambridge: Cambridge Univ. Press, 1984); Adrian Desmond, *The Politics of Evolution: Morphology, Medicine, and Reform in Radical London* (Chicago: Univ. Chicago Press, 1989); and James Secord, *Victorian Sensation: The Extraordinary Publication, Reception, and Secret Authorship of* Vestiges of the Natural History of Creation (Chicago: Univ. Chicago Press, 2001).

Russia, the claims of biological transformation and of scientific history were put forward by radical movements as a critique of church and state. Such debates and such ambitions soon reached well beyond Europe. Everywhere in the late nineteenth century, modernity was associated with science, social as well as natural, which was understood to be about technology and at the same time about being modern and enlightened. In Japan, China, India, the Near East, and Latin America, scientific knowledge and attitudes as well as new technologies were put forward as the proper means to break with the dead hand of the past and as key to the power and success of Europe and North America. As it became increasingly possible to earn a living practicing science, and as the enterprise grew by leaps and bounds, there rose up a teeming world of specialists. Nevertheless, it was also the golden age of popular science, manifested in best-selling books that interpreted science sometimes as a radical force, sometimes as a mainstay of established religion. Many of these books were by journalists, and some arose from Grub Street, but almost everyone who pretended to scientific eminence wrote and gave lectures for elite and popular audiences. The names of Hermann von Helmholtz and Ernst Haeckel, of Claude Bernard and Louis Pasteur, of Charles Darwin, T. H. Huxley, and Herbert Spencer, were as celebrated as those of presidents, business tycoons, and novelists.

Consider the phenomenon of Darwinism, often held up now as a key event in the professionalization of science. Very little of the controversy over evolution took place in specialist journals or disciplinary societies. From the Oxford confrontation of Huxley and Wilberforce to reviews in the *Edinburgh* and *Quarterly* to Salisbury's address to the British Association forty years later, the key debates on Darwinism were staged in full public view. Evolutionary naturalism was not an effort to draw sharp boundaries and exclude outsiders but to establish the cultural prominence of science and in this way to reshape society. This same ambition was reflected in the new prominence of a language of scientific method. That phrase, which exploded into prominence in the late nineteenth century, does *not* announce the hegemony of technical experts but, rather, a sense of science as a site of intellectual virtue and as accessible to everyone. The method of science was sometimes attached to strong claims for mathematical certainty but often assumed the form of a logic of probability, whose epistemological modesty was balanced by its unbounded extent. Scientific moralists invited people to apply this method in their everyday lives by setting aside prejudice and opening their minds to the evidence of the world. We might, looking backward, be moved to cynicism by cruel or unattractive policies that were defended in the name of science and by the implausible grandiosity of some schemes of human improvement, but this was a compelling vision for the nineteenth-century Enlightenment and for the scientists and others who held it aloft as a beacon.[25]

Contemporaries called it an age of science. We might want to amend that and call it an age of *public* science, to contrast with the image of a more technical and commercialized science, conducted on an immensely larger scale, that came into its own in the twentieth century. But we should not exaggerate the centrality of science to elite culture in the later nineteenth century. Science as we usually understand it was barely represented in the

[25] A few works on ambitions for science in the late nineteenth century: Frank M. Turner, "The Victorian Conflict between Science and Religion: A Professional Dimension," *Isis*, 1978, *69*:356–376, rpt. in Turner, *Contesting Cultural Authority: Essays in Victorian Intellectual Life* (Cambridge: Cambridge Univ. Press, 1993), pp. 171–200; Bernard Lightman, *Victorian Popularizers of Science: Designing Nature for New Audiences* (Chicago: Univ. Chicago Press, 2007); Deborah R. Coen, *Vienna in the Age of Uncertainty: Science, Liberalism, and Private Life* (Chicago: Univ. Chicago Press, 2007); and Porter, *Karl Pearson* (cit. n. 13).

upper administrative levels of the state, and an education in science was not the most promising route to power or influence. Classical education, sometimes supplemented by mathematics, continued to serve that function, and so it is highly significant that, along with their efforts to reverse their traditional subordination to religious authorities, the naturalists and advocates of science worked to justify its prominence in the curriculum as the basis for forming a cultivated individual. Huxley took this route in his famous exchanges with Matthew Arnold on science and culture. Arnold equated scientific education with instruction in a narrow, soul-numbing technical specialty. Huxley, who rejected the very label "scientist" as an American barbarism (about as felicitous a coinage, he said, as "electrocution"), insisted that, while the Renaissance had been correct to look for inspiration to the ancients, science was now the site of creativity and intellectual dynamism and the proper basis for forming a modern man. Science was not, for him, something remote and recondite, but "trained and organized common sense." In Germany, Helmholtz, son of a classicist, intoned that science provided a better training of the mind than Greek because scientific laws, in contrast even to those of a really dead language, admitted no exceptions.[26]

Such a melding of science and elite culture, as well as its diffusion into every corner of society, was part of Karl Pearson's mission at the turn of the twentieth century. He defended statistics, with its logical coherence and unlimited scope, as the proper basis for reconfiguring public life, for overcoming capitalist egoism and elevating disinterested knowledge based on facts. In America, Daniel Coit Gilman, founding president of Johns Hopkins University, articulated his vision by exalting the researcher as "the knight of the Holy Spirit of Truth" and condemning mere technical expertise. "A society made up of specialists, of men who have cultivated to the extreme a single power, without simultaneously developing the various faculties of mind, would . . . resemble a community made up of boys who can paint portraits with their toes, who can calculate like lightning, who can remember all the hats of the guests in a fashionable hotel, or perform innumerable feats on the tight-rope."[27]

And yet in Progressive America we find, possibly for the first time, a movement of educated people defending the sufficiency of technical knowledge. A leader of this social campaign was the mechanical engineer Morris L. Cooke, though it is necessary to add that by technical he meant technological, not narrow or specialized, and that his celebration of the engineer was wedded to a faith in scientific method in its most lyrical sense. He took very seriously the moral responsibility of engineers as well as their technical proficiency.[28]

For an idealization of the technician we can look to Thorstein Veblen, that most sardonic of Norwegians and inspired American. Veblen is famous for his sarcasm about the conspicuous leisure and conspicuous consumption of those late barbarians, the "captains of industry." But he also worshipped engineers and was a great champion of efficiency, which, he argued, could never be achieved by American capitalism because the

[26] Paul White, *Thomas Huxley: Making the "Man of Science"* (Cambridge: Cambridge Univ. Press, 2003); T. H. Huxley, "On the Educational Value of the Natural History Sciences" (1854), in Huxley, *Science and Education* (New York: Collier, 1902), pp. 40–86, on p. 46; and Hermann von Helmholtz, "On the Relation of Natural Science to Science in General" (1862), in Helmholtz, *Science and Culture: Popular and Philosophical Essays*, ed. David Cahan (Chicago: Univ. Chicago Press, 1995), pp. 86–87.

[27] Laurence R. Veysey, *The Emergence of the American University* (Chicago: Univ. Chicago Press, 1965), pp. 151, 161.

[28] Edwin Layton, *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession* (1971; Baltimore: Johns Hopkins Univ. Press, 1986).

greedy captains were utterly unqualified to rule over a machine civilization. In *The Engineers and the Price System*, first published as a series of magazine articles in 1919, he argued that a capitalist economy worked at all only because of technical experts, while the captains just got in the way. Veblen was responding to the Russian Revolution and to Lenin, a great supporter of scientific management who believed that, since Russia had barely experienced capitalism before making the next bold step into communism, it was desperately in need of efficiency. Veblen, wielding his ironies to fend off the Red Scare, declared that if there were to be a Bolshevik takeover in the United States, which was unlikely *at the moment*, it would be led not by untrained workers, who, after all, could no more direct American factories than could the financiers and bankers, but by technical experts, who indeed were running them already. Their competence is what really matters, while the capitalist types offer only illusion and sabotage—the latter deployed to keep prices up.[29]

Veblen's technicians were hired experts who could serve capitalists as well as communists, provided the atavistic culture of leisure and personal exploit did not interfere too much with their work. And yet he believed that their competence and efficiency would transform the social and economic system. Indeed, the rising importance of formal expertise in industry, war, and government has accelerated since Veblen's time, to the point that few human activities stand apart from the domain of technical science. Far from leading scientific experts openly to assume the reins of power, however, the expansion of the technical encouraged them to adopt a stance of neutral, self-effacing objectivity. Ironically, the pose of disengagement has become one of the key supports for the authority of science in regard to practical, contested decisions about public investment, medicine, public health, and environmental questions. And this objectivity works most effectively not at times of open political contestation, but when the experts act as cogs in the machinery of bureaucratic action, advising administrators rather than appealing to an engaged public.

Given the typical identification of science as public knowledge, it is ironic that war has been so central to the interactions of science and government. Science for military purposes often involves highly classified projects, such as radar and atomic weapons in the era of World War II. But the pressures of warfare have, especially in the twentieth century, created a demand for technical expertise to mobilize an economy and to make efficient use of resources, so that the work of scientists and engineers has reached beyond the improvement of arcane technologies to core functions of the state. Rarely, if ever, has science been so effectively merged into the bureaucratic elite as during the 1940s, and it was approaching its zenith just as C. P. Snow concocted his celebrated tale of two cultures. The new links of science to power put scientists in the unfamiliar position of being taken seriously when they complained of insufficient appreciation by a governing class of literary elites.[30] The proof of their success, as we should recognize, was their ability to mingle with government ministers and bureaucratic heads, rather than merely conducting research and writing official reports. But this influence waned with time, and postwar science never really connected with a wider public. The late twentieth century was marked

[29] Edwin Layton, "Veblen and the Engineers," *American Quarterly*, 1961, *14*:64–72; Thorstein Veblen, *The Engineers and the Price System* (1921; New York: Viking, 1933); and Kendall E. Bailes, "Alexei Gastev and the Soviet Controversy over Taylorism, 1918–1924," *Soviet Studies*, 1977, *29*:373–394.

[30] Thomas P. Hughes, *American Genesis* (New York: Viking, 1989), pp. 366–367, 378–379; and David Edgerton, *Warfare State: Britain, 1920–1970* (Cambridge: Cambridge Univ. Press, 2006), pp. 196–210.

by the ever more active role of the sciences, social as well as natural, in specialized problems of industry, administration, and regulation, accompanied by a rhetorical detachment from public roles, and certainly from public contestation, in the name of objectivity.

In his History of Science Society Distinguished Lecture in 1994, David Hollinger described the struggles in the 1940s and 1950s of American philosophers and sociologists of science, many of them Jewish, to uphold reason against its formidable enemies at home and abroad: Catholic sympathizers with fascism, totalitarian Nazis, and pro-Soviet Stalinists.[31] There is something heroic in the efforts of Karl Popper, Robert K. Merton, James B. Conant, and Richard Hofstadter to raise up the *scientific attitude* as our defense against the enemies of reason and tolerance. Yet their arguments are also paradoxical. The virtues of science were, for them, displayed in the technical achievements of the scientific community, not in the shaping of an enlightened public discourse. Their admiration for technicality became, after the war, the stock in trade of much American social science in the proud era of its own maturation. Sociology and economics, with their affirmations of professionalism and disciplinary competence, thus joined in the process they purported to describe, the advancing technicality of knowledge. Invoking Max Weber, who by 1945 was a figure to be reckoned with in American social science, they worked to ally scientific with bureaucratic rationality, and they insisted that the real work of science had to take place within professional academic fields.

In 1950s America, the socio-teleology of modernization exalted, as the natural outcome of history, relationships like those that postwar scientists had established with each other and with the machinery of state power. The ideal of technicality was a beacon for social science, whose leaders eagerly took up the quantitative technologies worked out by statisticians like Pearson and R. A. Fisher to situate themselves as unbiased experts, detached rhetorically from the fray of politics and ideology. A bit of the missionary ambition for science survived in their anticlericalism and their celebration of the scientific attitude as the successor to religion and magic, which must gradually be extinguished in an age of technological progress and of scientific and administrative rationality.[32] But they were not merely describing the institutionalized reality of twentieth-century science. The postwar social sciences themselves helped to establish the idea that science is fundamentally and intrinsically technical. Theirs was the generation for which it first came to seem self-evident that science moves naturally and inevitably toward the laudable insularity of "professionalization."[33] It was, after all, what they wanted for themselves, and their purportedly descriptive account of the natural development of science doubled as a teleology and as a normative standard. Natural and social science alike, they argued, form a world apart, one minutely subdivided, in which specialists can build up a body of shared knowledge and then, as appropriate, make the results available to outsiders.[34]

Of course I do not mean that science was easy and open until the twentieth century. Neither, however, was our modern configuration fixed by some moment of origin in

[31] David Hollinger, "Science as a Weapon in *Kulturkämpfe* in the United States during and after World War II," *Isis*, 1995, *86*:440–454.

[32] See, e.g., C. E. Black, *The Dynamics of Modernization: A Study in Comparative History* (New York: Harper & Row, 1966), p. 53; and Alex Inkeles and David H. Smith, *Becoming Modern: Individual Change in Six Developing Countries* (Cambridge, Mass.: Harvard Univ. Press, 1974), p. 28.

[33] Joseph Ben-David's important book *The Scientist's Role in Society* (Englewood Cliffs, N.J.: Prentice-Hall, 1971) is structured as an account of how science achieved professional self-determination.

[34] Nils Gilman, *Mandarins of the Future: Modernization Theory in Cold War America* (Baltimore: Johns Hopkins Univ. Press, 2003); and David Paul Haney, *The Americanization of Social Science: Intellectuals and Public Responsibility in the Postwar United States* (Philadelphia: Temple Univ. Press, 2008).

ancient Greece or the seventeenth-century Scientific Revolution. On the contrary, there have always been living alternatives. The elite reformers of American science education in the 1950s tried to represent science as a fundamental part of the Western cultural tradition, and we find that spirit reflected also in James B. Conant's project for history of science at Harvard (and the nation). Humanists, lawyers, business leaders, and statesmen, he argued, need to understand the spirit of science. Thomas Kuhn's 1957 study of the Copernican Revolution, with its attention to Renaissance philosophy as well as mathematical astronomy, is an exemplary product of this program. Exemplary also is Kuhn's thesis that a medieval cosmology of long standing was undercut by mathematical anomalies in astronomy. Historians, and citizens, ignore technical science at their peril.

The defense of science in the contemporary era has put particular stress on technical achievement. British as well as American postwar scientists let on that the Nazis lost the war because wild romanticism disabled them technologically. Albert Speer successfully inverted this argument, claiming that he had brought technical efficiency to Nazi economic and industrial policy and, on this evidence, that he could not have been a full-blooded Nazi.[35] This was plausible to many even among Germany's wartime enemies—and indeed to the Nuremberg judges, who gave him a comparatively lenient sentence, though Speer's economic miracle has since been reduced by economic historians to a myth. More to the point, bizarre Nazi ideologies coexisted perfectly well with full technical competence in the production of weapons and the organization of war. To be sure, their greatest feats of technical virtuosity were associated with visionary projects like the V-2 missile, which did not really help the war effort.[36] By 1960, sober-minded observers were again beginning to doubt that the work of science has much to do with critical reason or public enlightenment. Thomas Kuhn, reacting to Popper's and Merton's bright image of scientific reason, interpreted the little communities of specialized science as scenes of indoctrination, not of skeptical inquiry, in a way that at first seemed disturbingly radical. And Charles Gillispie, who dissented from Kuhn on scientific revolutions, was convinced that technical science had worked pretty well under ideologically closed dictatorial regimes, not excluding those of Hitler and Stalin, and provided no bulwark against the enemies of freedom and tolerance.[37]

Modern techniques of obfuscation, pioneered by tobacco interests and skillfully deployed by energy and pharmaceutical companies and by religious opponents of evolution, have stimulated modern-day scientists to try to clarify in a more public way the standards of scientific reason. Since the tricksters come soberly dressed in lab coats, speaking cautiously of the need for more research to attain an acceptable standard of certainty, the refutation has to be still more subtle and to penetrate beneath the surface. But nuanced argument in defense of science goes against the grain. Scientific knowledge is more often idealized as *information*, which renders craft invisible. As Yaron Ezrahi points out, information means knowledge that is ready-made for deployment by anybody, requiring

[35] Soraya de Chadarevian, *Designs for Life: Molecular Biology after World War II* (Cambridge: Cambridge Univ. Press, 2002), p. 25; and Adam Tooze, *The Wages of Destruction: The Making and Breaking of the Nazi Economy* (New York: Viking, 2007), p. 552.

[36] Our more recent experience of missile defense does not encourage the supposition that only fascist regimes are vulnerable to scientific reveries of this kind.

[37] Thomas Kuhn, *The Structure of Scientific Revolutions* (Chicago: Univ. Chicago Press, 1962); and Charles Gillispie, "Remarks on Social Selection as a Factor in the Progressivism of Science" (1968), rpt. in Gillispie, *Essays and Reviews in History and History of Science* (Philadelphia: American Philosophical Society, 2007), pp. 366–378. See also Gillispie's new introduction to his review of Kuhn's *Structure*, "Thomas S. Kuhn: The Nature of Science," *ibid.*, pp. 341–342.

no interpretation. We can call it *thin description*. The "information society" is practically synonymous with modernity.[38]

This form of knowing fits also with the modern accommodation between science and the state. Science, since World War II, has been funded at levels that would have been unimaginable just a decade or two earlier. But implicitly it is presumed that science will keep clear of politics, and in America at least the leaders of science have become nervous also about offending against religious beliefs. As Oppenheimer's security hearings showed, qualified scientists were permitted to discuss among themselves the technical feasibility of the hydrogen bomb, but it was not their business to question the desirability of building such weapons or to propose institutional arrangements by which they might be regulated. An idealistic left-tending movement of scientists nevertheless did mount an educational campaign regarding the basic physics and the policy implications of nuclear weapons. This put them at odds with the Cold War state, and it also went against the dominant perspective among social scientists, who in recent times have been more cynical than physicists and engineers about the capacities of the lay public. Invited to assist in the effort, they helped to divert it by introducing the advertising techniques of opinion management.[39]

We hear often of the great prestige of science in the modern world, and in a way this is valid, but that prestige refers to something special: absolute authority over a specific (technical) domain and restraint from meddling elsewhere. The scientific ideal of reason is a highly constrained and exacting one, and (to revise Wittgenstein) it demands silence when one cannot speak definitively. Technicality has become not merely one key aspect of science but its defining characteristic. And yet reverence for the technical tends to breach the walls that confine it. In the guise of technicality, scientific findings can be decisive for public decisions. Tools such as cost-benefit analysis, risk analysis, and controlled experiments yielding adequate significance levels have recognized legal standing in regard to policy choices involving transportation, pharmaceutical licensing, and industrial health issues. Many difficult scientific questions, such as the proper definition of a species or the threshold of carcinogenic risk for a chemical, come very close to dictating policy outcomes. The political process itself demands the authority of objectivity on many matters, and so science presses, and is pressed, relentlessly outward.

Hence the divide between technical science and political opinion is highly unstable. The currents of science and technology overflow everywhere the boundary between ought and is. In an age of opinion polling and the use of brain scans to gauge the effectiveness of campaign advertising, political discourse itself has become permeated by technical knowledge. Our modern compact between science and the state, which consigns science to the domain of positive fact, is itself in many ways a fiction, for the role of the sciences in regard to public issues of all kinds has never been more encompassing. Yet that fiction shapes our public engagement with science—and even what we mean by science. Tech-

[38] Allen Brandt, *The Cigarette Century: The Rise, Fall, and Deadly Persistence of the Product That Defined America* (New York: Basic, 2007); Robert N. Proctor and Londa Schiebinger, eds., *Agnotology: The Making and Unmaking of Ignorance* (Stanford, Calif.: Stanford Univ. Press, 2008); Yaron Ezrahi, *The Descent of Icarus: Science and the Transformation of Contemporary Democracy* (Cambridge, Mass.: Harvard Univ. Press, 1990); and Ezrahi, "Science and the Political Imagination in Contemporary Democracies," in *States of Knowledge: The Co-Production of Science and Social Order*, ed. Sheila Jasanoff (New York: Routledge, 2004), pp. 254–273.

[39] On the scientists' educational campaign see Jessica Wang, *American Science in an Age of Anxiety: Scientists, Anticommunism, and the Cold War* (Chapel Hill: Univ. North Carolina Press, 1998). On social science and the American public see Christopher Lasch, *The True and Only Heaven: Progress and Its Critics* (New York: Norton, 1991), Ch. 10.

nicality was not created simply by the proliferation of scientific specialties, though of course they foster technical methods and discourse. Its meaning has also been shaped by social theories and interests regarding science and by new public expectations of it.[40]

When science denies its own depth in favor of pretending to the straightforward application of method and the production of information, it participates ironically in the anti-intellectualism it otherwise purports to combat. And yet on this field of struggle it is bound to be outmaneuvered by the real opponents of truth, masters of scientific disguise, who sow doubt everywhere by claiming that what threatens their interests has not followed the rigorous standards of "sound science."[41] Thus is science hoist on its own petard. And for that reason, I consider that the historical and social study of science, which as we all know has sometimes been criticized as postmodern nihilism, is a necessary ally of scientific reason. The contribution of historians is to analyze more richly how the work of science is done and to explore in depth its interactions with the larger culture. It is neither truthful nor advantageous to pretend that science by its nature is detached from the world or that it can be sovereign on an island of technicality.

For nearly half a century, the best practice in history of science has meant explaining past science in its own terms rather than assessing it against the inflexible standard of the present. The worlds opened up by historicism are fascinatingly different from our own, seemingly irreconcilable with it, yet linked genetically to what comes after. To historicize the scientific life and its relation to polities, economies, and societies makes visible the action of intellect beyond the blockade of professionalization. Knowledge under a regime more open and more modest might be put to work more honestly amidst the contingencies of the world. Science knows more possibilities than this sociology and this history have imagined.

[40] Sheila Jasanoff, *Designs on Nature: Science and Democracy in Europe and the United States* (Princeton, N.J.: Princeton Univ. Press, 2005); and Porter, "Speaking Precision to Power" (cit. n. 2).

[41] Chris Mooney, *The Republican War on Science* (New York: Basic, 2005).