Chapter Twenty-Five

The Century of Science

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Max Weber's master narrative of the nineteenth century, outlined in *The Protestant Ethic and the Spirit of Capitalism* (1904–5) and other works, rested squarely on an understanding of science and the forms of rationality associated with it. In his view the unfolding of the Enlightenment promise of progress and emancipation through the application of reason came to a crashing halt in the years prior to World War I, the *terminus ad quem* of the century. Weber expressed his pessimistic views on modernity in many ways, but none is more memorable than his phrase "the iron cage," a physical and visual metaphor for the perceived separation of reason and values. This indictment of modernity, echoed by scholars since, has been responsible for a separation of another type: the separation of science from a broader historical understanding of the century.

Although historians have paid lip service to Weber's interpretation, few have integrated the salient categories of Weber's analysis – in particular scientific culture and bourgeois rationality – into their interpretations of the nineteenth century. The fault is in part the result of a professional division of labor. Historians generally leave the task of interpreting science to more specialist historians of science, and the task of interpreting rationality either to philosophers or intellectual historians. The result is a bifurcated history that fails to address adequately the complexities of lived historical reality in the nineteenth century, not only of the roles of science and technology in it, but also of the ways social groups appropriated reason, reasonableness, and rationality for their own ends. The story of science *in* nineteenth-century European history thus remains for the most part an unfinished project.

Yet the nineteenth century was a "century of science." From the French Revolution to World War I the scientific disciplines – both natural and social – took shape; the scientific persona in the form of the professional scientist emerged; and scientific institutions in the form of popular clubs, specialized academies and institutes, research laboratories (both pure and applied), technical government agencies, and educational curricula at schools and universities became embedded in European life. The scientific community and its institutional system of support became an integral part of everyday life as well as high politics. Science, its technical practices, and its rational ways of thinking contributed strongly to the shaping of the self, society, and the state – so much so that by the end of the century it was not unusual to find social issues treated as technical problems in the application of rationality. No wonder then that Weber and like-minded social scientists such as Émile Durkheim spoke of modernity in Janus-like terms: condemning it for its emphasis on reason and the sciences, but also supporting its reliance on the social sciences to provide the diagnostics and therapeutics that could lead to reform and betterment.

The Landscape of Science

The emergence of the natural and social sciences in the form of disciplines after 1800 represented a radical intellectual and social departure from earlier conceptions of knowledge. Until the seventeenth century the scholastic curriculum organized knowledge into the seven liberal arts (astronomy, music, geometry, arithmetic, rhetoric, grammar, and dialectic) and philosophy (logic, ethics, and physics). During the eighteenth century, knowledge – including natural philosophy, which embraced most of what became known later as the natural sciences – was regarded in theory as a unity best represented in encyclopedias or compendia. Although specialization occurred in practical areas like astronomy, forestry, and in other domains strategic to the state and the operation of the economy, such fracturing was not ideal, was generally associated with the arts and trades, and was epistemologically inferior to more encompassing forms of knowledge. The court, the state, and the academy were the principal patrons of natural philosophy on the continent, while in Great Britain the natural philosopher found an audience in the public sphere and a patron in the state bureaucracy. All over early modern Europe the Catholic church was exceptional among all institutions in its support of astronomy. Universities, by contrast, had not yet institutionalized intellectual innovation to any great degree. The eighteenth-century belief in the "unity of knowledge" was difficult to eradicate. Even after the emergence of the disciplines with their sharply defined intellectual boundaries, a belief in unity persisted in the German ideal of *Wissenschaft* and in British and continental Romantic science, but both proved incapable of surviving the more thoroughgoing intellectual and social transformations associated with the disciplines.

Historians know more about how rather than why sharply defined areas of knowledge with their own methods, problems, and practitioners took shape after 1800. Specialization in the physical sciences occurred first (due in part to a rapid adaptation of methods from astronomy), in the life sciences around mid-century, and at the end of the century, the social sciences. The process was not merely intellectual. The modern disciplines were also characterized by institutionalized systems of training, recruitment, and professional behavior, as well as specialized forms of association and communication (professional societies and journals). Sociologist Rudolf Stichweh, among others, has drawn connections between the rise of the middle class and the appearance of disciplinary knowledge in the German states: the two developments intersect in the state examination system for credentialing bureaucrats and other functionaries that became a route to social advancement for the educated middle class.[1] Historian R. Steven Turner has called the Prussian examination system, to take one prominent example, a "powerful instrument of modernization within the professions."[2] Similar connections between scientific knowledge, social mobility, and professional careers in both state service and the sciences were also found in the Cambridge Mathematical Tripos in Great Britain[3] and more generally in the French Grandes Écoles. Goethe's *Faust* (1806) projected anxiety about the volatile combination of ambition, power, and knowledge, but in reality all European state examination systems created avenues of upward social mobility based on the free expression of talent, concentrated training, and superior academic achievement.

No factor was more important in the social reproduction of individuals dedicated to knowledge production than the sharpening of the identity of those who studied the natural (and later, social) world. In previous centuries philosophers, academicians, bureaucrats, and others studied nature by avocation. Those who excelled at it were called "geniuses" until the 1830s; but genius by definition was believed to be a personal gift, and so could not be systematically reproduced by institutional means. Debates early in the century over the notion of genius bespoke a deep-seated change in the role of natural knowledge in the public sphere where it was democratized, criticized, but most of all, accessible. Coincident with the emergence of the disciplines and the pedagogical means for teaching them, the scientific persona took shape. A debate in the British Association for the Advancement of Science over who exactly the motley crew of individuals were who purported to study natural philosophy prompted Samuel Coleridge to ask the polymath William Whewell to think of a moniker appropriate for them. He did, and in 1834 coined the word "scientist" for those engaged in the study of nature; by the end of the century it applied to those who studied the body, the mind, and society as well. Within decades thereafter genius became a term of derision, suspicion, and distrust because it connoted privacy and secrecy, rather than public knowledge and openness. Only in undertakings that could not be completely taught or codified – such as art – did the term genius retain currency and respect.[4]

The emergence of science as a vocation in the nineteenth century was thus an affirmation of the social investment in pedagogical systems designed to create types of individuals – experts – whose qualifications were certified by institutional and often state-sanctioned standardized rules of judgment. But the very same educational systems that were responsible for turning out scientists also acted as sieves that allowed only certain types of individuals to do so. For most of the century the gender barriers of higher education prevented women from becoming scientists. *Pace* Max Weber's later contrast between science and politics as vocations, the scientific persona in the nineteenth century took shape within a moral space – as Charles Taylor wrote in general about the modern self – within which certain actions and behaviors were imbued with virtue, such as the open disclosure of sources, the honest reporting of data, and the meticulous calculation of errors of measurement.[5]

A complex system of social reproduction appeared simultaneously with the emergence of the scientific disciplines, especially in universities where the training of the next generation of practitioners took place. German universities took the lead in training natural scientists because they integrated research and teaching early in the century, but by the end of the century nearly all European universities had followed suit. Secondary schools were important partners in sustaining social reproduction in the natural sciences and mathematics through their employment of university-trained teachers and their ambitious efforts in reforming science pedagogy across the century. The intensification of industrialization in the second half of the century aided the coalescence of two curricular tracks in secondary and tertiary education: classical and "modern." The success of technical education in the sciences and engineering was based in part on its appeal to the middle and lower middle classes.

The scientific disciplines congealed as coherent bodies of knowledge with enough structure to be passed on to the next generation, thereby facilitating social reproduction, but also enough fluidity to allow for modifications through research. The principal site of scientific research was the university-based laboratory or institute, and later in the century, industrial laboratories, state agencies, and privately funded research institutes. The earliest university-based scientific laboratories and institutes were in chemistry, but after about the 1860s specialized facilities for physics grew markedly due to the close ties between industrial culture and measuring practices and the need to train the next generation in techniques of measurement. These physical laboratories and institutes, in which Germany first took the lead, were found primarily in industrializing regions, dedicated themselves primarily to teaching, but also served as important centers of social interaction. With simple origins in glass-walled cases known as cabinets for housing instruments, physical institutes grew to include research and teaching laboratories, lecture rooms, and smaller rooms for individualized study and practice. Some even included apartments for institute directors. Between 1865 and 1914, German universities possessed 21 such institutes. Facilities outside Germany were more modest by comparison. The Cavendish Laboratory of the University of Cambridge, for instance, opened in 1871 under the direction of James Clerk Maxwell; until 1879 its modest research agenda included nothing more interesting than research on electrical units, then a matter of international debate. Women were finally admitted in the early 1880s, a novelty in European higher education. Not until the end of the century did the Cavendish offer degrees (bachelor's and master's) to students who had not matriculated at Cambridge as undergraduates, a condition that had inhibited the types of international visitors that frequented German laboratories and institutes.[6]

These intellectual, social, and institutional changes based largely in European educational systems by no means constituted the entirety of scientific culture. Some traits of eighteenth-century natural knowledge persisted, albeit now absorbed into new administrative and institutional frameworks. Public service work, for instance, still tied science to the state. Astronomers such as George Airy in Great Britain, Friedrich Wilhelm Bessel in Germany, and François Arago in France contributed to projects like weights and measures reform, military and cadastral mapping, meteorological data, and insurance and other practical issues. Outside the university, professional societies like the British Association for the Advancement of Science (founded 1831) and a rich journal culture sustained intellectual communication among scientists, while civic associations dedicated to science and technology promoted exchanges in the public sphere between scientists and society, integrated scientific discourse into daily life, and encouraged rational solutions to agricultural and economic problems.[7] After the mid-century revolutions on the continent a popular journal culture dedicated to nature and the natural world spread the ideas, rational ways of thinking, and ethos of the natural sciences.[8]

By the end of the century the landscape of scientific culture included not only educational institutions, industries, and civic associations, but also industrial laboratories, national laboratories, and privately funded institutions for scientific research. The first industrial laboratories appeared after 1860: outstanding examples include Alfred Krupp's chemistry laboratory at his Essen steel foundry; chemical testing laboratories associated with foundries around Sheffield, England; the organic chemistry laboratories established in Britain, France, Switzerland, and Germany following the discovery of synthetic aniline dyes in 1856; and the laboratories of the burgeoning electrical industry, including Siemens & Halske in Germany and Philipps in the Netherlands, dedicated to research and development in communication (including the telephone), artificial lighting, and in utility supply and regulation. University laboratories, whose directors had the added responsibility of teaching, proved incapable of both sustaining innovation and handling state responsibilities. As a result, European governments established large-scale national laboratories to handle basic research as well as testing in the name of public safety and consumer protection. The first of these was the Berlin-based Physikalisch-Technische Reichsanstalt (1887), followed by the National Physical Laboratory in Teddington, England (1899). Also inaugurating the era of "big science" was the establishment of private research institutes, such those of the Kaiser-Wilhelm-Gesellschaft in Germany, whose first institute opened in 1911.[9]

The conceptual landscape of the natural and social sciences was by then marked by ideas and theories that were both research subjects for practitioners and a new conceptual framework for interpreting the quotidian. Terms that crossed the divide between science and society included: energy, entropy, electrical current, and electromagnetism from physics; cell and evolution from the biological sciences; probability, uncertainty, and non-Euclidean space from the mathematical sciences; and anomie, ego, and subconscious from the social sciences. The institutionalization and professionalization of science in the nineteenth century thus was not only a sign of the socialization of science, but also the scientific rationalization of society.

Science and the Definition of the Self

Over the course of the nineteenth century the rational discourses of the natural and social sciences as conveyed primarily in medicine and public health redefined the body and mind as entities that could be known through the specialized language of experts rather than through religion as they had been for so long. The growing interest in body types – the result of social change, the photograph, and physical anthropology – destroyed the Enlightenment's belief in natural law with its assumption that the commonalities of humanity were far more important than any environmentally caused differences. Social scientists, physicians, and psychiatrists isolated individual and group differences ostensibly to create classifications, but the inevitable result was the construction of hierarchies cast in the vocabulary of the physical and biological sciences. In England, France, and Germany psychiatry became an important means through which the middle class articulated its own identity by defining normalcy in terms of rationality or the absence of mental illness. The latter was, in any event, easier to define. Race and gender proved to be the most malleable traits in the scientific construction of the self. Paul Broca's Anthropological Society of Paris created a racial typology based on phrenology in the 1850s, while anthropometry served equally well in confirming the inferiority of women or the pathological, atavistic physical type characteristic (in Cesare Lombroso's mind) of the criminal. In the 1890s Jean-Martin Charcot used the camera to document a physiognomy of insanity that became an iconography of mental illness. In all of these examples the sobriety of scientific investigation was compromised by political uses of the aesthetics of objectivity, usually in support of the status quo.[10]

Although the burgeoning reading public of the eighteenth century helped to shift the emphasis from the sense of hearing to that of sight, vision became the key sense of the nineteenth century through science and technology. The transition from an aural culture to a visual one was the result of the massive reorganization of knowledge leading to the formation of the disciplines; of the shift from an *a priori* to an empiricist theory of vision; and of the introduction of several new visual technologies. The first two changes were linked. Older theories of vision, including that of Immanuel Kant, regarded the sense of sight as *a priori* or innate and the eye as a camera obscura. But between 1810 and 1840 a subjective theory of vision grounded in physics and physiology took shape, with elements from the study of color perception, nerve impulses, and after images. A physiological optics that capitalized on the imperfections of the eye replaced the objective geometrical optics of the camera obscura and its mathematical space grounded in perspective.[11]

The transition from an innate to an empiricist theory of vision coincided with the fascination with optical illusions in everyday life, as are found in the stories of E. T. A. Hoffmann wherein new social groups, new urban spaces, and new mechanical devices challenged customary patterns of recognition. The railway journey reorganized space into what Wolfgang Schivelbusch has called "panoramic vision": the view of the landscape from a train window, framed by telegraph poles.[12] The play on visual illusion occurred also in new visual forms like the panorama, introduced by Robert Barker in Edinburgh in 1787, and the diorama, first created in Paris by Charles-Marie Bouton and Louis Daguerre in 1822, as well as in new visual technologies, such as the kaleidoscope (1822), the thaumatrope (1825), the phenakistiscope (1833), and the stereoscope (1838). All became mass produced, commercialized popular toys by mid-century. Especially crucial to the transformation of the visual experience in the nineteenth century was the stereoscope, invented by David Brewster. It highlighted the persistently unstable and subjective nature of vision by playing on binocularity and depth perception. The stereoscope subverted the type of contemplation associated with the camera obscura and perspective. Instead, the new observer had to *learn to see* and could only see within a prescribed set of possibilities. This empiricist theory of vision placed sight within a field of physiological and mental operations that constantly tested and verified experience. At the end of the century mass produced items, the visual array of images, and the frenetic pace of life characteristic of industrial culture (especially in the workplace and the marketplace) led to concerns about visual distractions that caused inattention, lowered productivity, and induced neurasthenia. Hence the attempt not only to stabilize perception through the teaching of precision measurement, perspective, or geometrical drawing, but also to understand the scientific foundation of inattention and exclusions of the visual field by analyzing visual reaction times, a popular subject of psychological investigation.[13]

Numbers also defined the self in the nineteenth century. The Enlightenment had its "reasonable man," but the French Revolution and the terror that followed gave pause to the idea of rationality or reasonableness as necessarily defining the self. Individuals were, in any event, fickle, idiosyncratic, and difficult to pin down precisely. Far more reliable and predictable, the Belgian statistician Adolphe Quetelet argued, was *l'homme moyen*, the average man. Measuring the traits of individuals (height, weight, age at marriage, fertility, mortality, and other traits), Quetelet found that the distribution of measurements followed the same bell curve that Carl Friedrich Gauss had identified as governing the distribution of errors in observational astronomy. In his "social physics" of 1831, Quetelet introduced his average man as the foundation of the broad laws of social behavior that could be incorporated into legislation aimed at reform. Or, more appropriate to his age of revolution, the calculation of averages from year to year could lead to the isolation of perturbations to which an opposing force (reform legislation) could be applied to neutralize potential social uprisings. (Hence, the collection of statistics soared in the mid-century revolutions, 1848–52.) Whether in good times or bad, the average man was the essence of mass society. Embodying the virtue of temperance, he was the moral ideal of an age in constant fear of losing its bearings.[14]

Science and the Construction of Society and Communal Spaces

Although Europeans possessed ways of speaking about society in the eighteenth century, the French Revolution and industrialization spurred new ways of thinking about social groups and of the operation of society as a whole. Both changes separated civil society from the state, and acknowledged the properties of groups of individuals separate from politics. Nonetheless, the politically motivated gathering of statistics by governments after 1800 – in censuses, crime rates, suicide rates, and the like – provided the first inkling that there was an order to individuals gathered together in groups. "Society" emerged as a concept linked to numbers in statistics. Not until the end of the century, though, did a science of society – sociology – appear as a full-fledged discipline. The numbers that had by then defined social regularities were the foundation for articulating the normal and the pathological in terms of what Émile Durkheim called social facts: institutional norms that prescribed ways of acting within certain limits, thus functioning as behavioral constraints. Hence Durkheim could argue in *Suicide* (1897) that anomie or the absence of communal norms created pathological states such as high suicide rates, which were the manifestation of institutionalized egoism, the opposite of communal norms.

Historians customarily associated the formation of civil society in the eighteenth century with reading clubs, but the transformation of the public sphere in the nineteenth century was due in large part to the integration into it of the rational discourse of communication associated with the natural sciences. During the eighteenth century in Britain chemistry and civil culture developed symbiotically,[15] but it was not until much later that the integration of science and civil society occurred on the continent, where the surge in associational life in the nineteenth century occurred in part as a result of popular interest in science and technology outside the university, the institute, and the academy. Far from being merely a popular exposition of the ideas and theories of the natural sciences, the scientific culture that thrived in civil society was a nursery for the bourgeois virtues of toleration, openness, and rationality.

Science and technology provided the vocabulary and the material means to articulate the finer details of communal spaces, especially urban ones. Artificial light, in particular electric lighting, produced a pluralistic visual environment in Europe's urban areas now subject to the optical control of space. The gas lamp (1810s), and especially electric lamps (1880s), changed street life by facilitating greater surveillance by authorities, by creating night life, and by introducing psychological transformations in the perception of night and day. Paintings like Vincent Van Gogh's *Café Terrace at Place du Forum* (1888) are illustrative of the nocturnal spaces and activities – such as *flânerie* – created by an artificial light that competed with heaven's stars. Dark areas of the city drew the attention of police, for they were associated with criminality. During the revolutions of the 1830s street lanterns were so identified with state authority that lantern smashing became a form of rebellion – as well as a way to reappropriate the street from authorities, as the street urchin Gavroche did in Victor Hugo's *Les Misérables* (1865). Unlit spaces generated nocturnal insecurity, one of the many new psychological feelings spawned by science and technology.[16]

Physiology, chemistry, and biology became municipal sciences that united the laboratory culture of the scientist with the urban environment of water, pollution, epidemiology, and public health. Urban sanitation movements – including sewer systems, water hydraulics, and bathhouses – coincided nearly exactly with the mid-century revolutions as well as with the increase of air pollution caused by factories (especially chemical ones) and the switch from wood to coal as the primary fuel. Edwin Chadwick's sanitary movement in England after 1846 associated communal bathhouses with the mission to civilize the working class; Baron von Haussmann's Parisian sewers of the 1850s were in part intended as a bulwark for the moral order of society; and Hamburg's sewer and bathhouse reform of the same period, inaugurated by the Englishman William Lindley, was built on the belief that dirt and pollution spread disease and disorder while cleanliness promoted public order. The internationally known German chemist Justus Liebig argued in 1844 that soap was the measure of the prosperity and culture of the state (only to be contradicted later by Heinrich von Treitschke, who remarked that the British conflated soap and civilization). The fact of the matter was that most urban cultures vacillated on the issue. In Hamburg, for instance, where public baths had been closed in the eighteenth century in the belief that they were a source of disease, less than half the population regularly took a bath at the end of the nineteenth century. The nineteenth-century public health movement, built on the principles of scientific medicine, mixed politics and scientific rationality in its emphasis on circulation as the guiding metaphor for the "air and light" movement that governed urban planning. But cleanliness in the second half of the century was more than a matter of health and hygiene: it became a marker of bourgeois distance not only from dirt and pollution, but also from the criminal, the disorderly, and the dangerous. The quotidian appropriation of principles from science and medicine enacted in the use of water technologies thus contributed to bourgeois traits and values.[17]

Yet when the collective health of individuals became the index of the entire social organism, as it did in the second half of the century, the physician, physiologist, chemist, and biologist all became *de facto* agents of the state acting for the social good. Whereas in the 1860s and 1870s liberalism and free trade upheld the noninterventionist state, capitalist cycles and their deleterious consequences later in the century opened the door for interventionist policies guided by experts. The germ theory of disease – supported by the discovery of the bacteria for anthrax in 1876 and for tuberculosis in 1882 – prompted policies to eliminate dirt, both material and social. The growing consensus in the 1880s that chromosomes were the heredity substance in the cell nucleus responsible for passing on traits – a belief reinforced by the rediscovery of Gregor Mendel's laws of inheritance in 1900 – shifted attention away from the environment and toward the biology of reproduction as a way to reduce the occurrence of undesirable social, mental, and physical traits. Taken to the extreme, selective breeding became racial hygiene: a politics of healthcare based on biological heredity as a means of controlling pathological behavior. Racial hygiene was also perceived as an effective antidote to social welfare because rather than protecting the weakest elements of society, it sought to eliminate them. In seeking rational solutions to social problems, scientific medicine and a public health grounded in scientific principles led to the invasion of the vocabulary of the life sciences into politics, economics, and civil society, as well as to the integration of scientific experts into the state bureaucratic apparatus.[18]

Science and the Nation-State

Scholarship since Michel Foucault's *Discipline and Punish* (1977) has supported his thesis that the modern liberal state is in part upheld by the sciences of the body and the mind, especially psychiatry and psychology, scientific medicine, criminology, and pedagogy. A closer examination of the relationship between knowledge and the state demonstrates, however, that nearly all the natural and social sciences were deployed in the construction of the sinews of the types of dispersed power that Foucault believed existed alongside the traditional expressions of state sovereignty, including the military and the police. In the second half of the century most European states used scientific expertise for social welfare, political administration, and economic productivity. By World War I, they had in addition established agencies for uniform weights and measures, health policy, materials testing, industrial codes, and other matters – all in the name of national security, public safety, public health, consumer protection, social welfare, and the overall wellbeing of the state. Regulatory agencies established uniformity in the material world and concepts of "normalcy" for the social world. Indeed, as the century drew to a close, state sponsored social hygiene became closely allied to eugenics as a means to counteract perceived social degeneracy caused by industrialization. The preference for protecting and policing society over preserving individual rights extended to the science of criminology: throughout Europe crime became more a matter of social hygiene than retributive justice.

The state's use of science and technology for its own political ends was not new to the nineteenth century, as several examples from the eighteenth century illustrate. In 1714 when Isaac Newton was himself in state service as warden of the mint, Queen Anne established the Board of Longitude by an Act of Parliament and launched a competition aimed at securing a means for the accurate determination of longitude at sea, a race in which the English cabinet- and clock-maker John Harrison proved victorious over Europe's professional astronomers. Nearly all German-speaking states in Central Europe used cameralism as a way of harnessing the state's considerable resources, from silver mines to the population at large. Embracing both baroque classificatory schemes and the emancipatory goals of Enlightenment reason, cameralists viewed science and technology as suited for reform, repair, and reinstatement of social order. Science and technology were integrated into the French state like no other. The science of cartography literally defined France from the ground up: four generations of the Cassini family of astronomers created the first accurate national map based on triangulation, published between 1798 and 1812. And when the revolution recreated the state anew, scientists were once again central to the process in the creation of the meter, the new revolutionary unit of length, defined as 1/10,000,000 of the meridian running through Paris, measured from Dunkirk to Barcelona and expressed in the form of a platinum bar cast in 1799.

What continued into the nineteenth century in the relationship between science, power, and the state was the overwhelming reliance upon quantification in the acquisition, interpretation, and representation of knowledge, but now stripped of the Enlightenment's belief in the absolute certainty and objectivity of results. Both numerical tabulation and measurements were subject to the statistical assessments of methods based on probability calculus; even the most exacting of precision measurements (say those taken in triangulation projects) were subject to the method of least squares and its probabilistic determination of the limits of certainty. Despite the uncertainties of quantitative results, most European administrators remained firm in their resolve to continue to use them as a foundation for policy. In their support the Statistical Society of Paris proclaimed in 1860 that statistics was an indispensable science for the liberal state and for good governance of society, and later in the century the French Academy of Sciences admitted that numerical results in any event constituted transparent facts about the world. European nations in essence defined themselves through the tools that became a part of the social sciences. The populace tended to view surveys – such as the compilation of vital statistics in France or taxpayers in Great Britain – as state intrusions into private life, but they became essential information for bettering administrative services, economic productivity, and even physical infrastructure by mid-century. Alexandre Parent-Duchâtelet's statistics on prostitution in Paris of 1836 were, for instance, viewed in conjunction with the planned installation of a new sewer system as a part of the overall effort to institute a culture of cleanliness in service of public health.

The most visible manifestation of the relationship between science and national identity was the construction of state maps based on triangulation, precision measurement, and the surveyors' instrumentarium of theodolites, sextants, calipers, thermometers, telescopes, heliotropes, repetition circles, plumb lines and levels, comparators, and metal bars for laying out baselines. Whereas in the eighteenth century cartography was a military exercise in preparation for war, in the nineteenth century military officers worked side by side with state astronomers to define the geography of the state by geometric means. France took the lead during the Napoleonic period by attempting to extend the Cassini map to newly conquered lands, but Switzerland is perhaps the best example of the union of power, knowledge, and space in mapmaking. The construction of the first trigonometric and topographic map of Switzerland took place under the direction of General Guillaume-Henri Dafour between 1832 and 1865, coinciding with the constructive phase of Swiss liberalism between 1830 and 1848. The map provided not only the first bird's-eye view of the country, but also the physical space of military, transportation, communication, and hydraulic projects. Indeed, it is argued that the idea of "Switzerland" as a cartographic entity preceded the full realization of the definition of the nation.[19]

Even more than cartography, statistics and other sciences defined the nation, and they defined the most unwieldy of nineteenth-century political entities, the empire, and none more than the British Empire, and within it, India. The idea that possession of science and technology was a yardstick of civilization was already centuries old by the time Britain brought irrigation, the railroad, the telegraph, and other technologies to Indian soil. Rather than defining India similar to the way in which they had defined Britain, these technologies instead necessitated administration and governance by the occupying power and those who cooperated with it, and thus consolidated the empire. No printed work shows more clearly the connection between scientific data collection and empire definition than Rudyard Kipling's *Kim* (1901). Throughout the novel, scientific knowledge is used to stress power relations, subject a people and remove agency from them, and illustrate the superiority of Western rationality over Eastern irrationality. Kim himself is a surveyor trained in one of the most disciplined mathematical practices of the nineteenth century, but under the guidance of the obsessive collector of ethnographical data, Colonel Creighton, Kim "surveys" by other means, joining Creighton in a massive spy operation designed to prevent rebellion and maintain the empire. Both of them were agents of the massive deployment of resources to gather scientific data about the empire – so much so that some historians have argued that the empire existed only on paper, in the files of the British Museum. Science and technology thus helped the British to conceive of an empire distant in space and culture; to construct hierarchies based on racial and national stereotyping and on the possession of rational knowledge, and to transform the definition of "classified" from mere organization to secret state knowledge. Whether in British India, German Southwest Africa, or the Belgian Congo, the rational sciences were an important part of the combined European imperial project.[20]

An Example from Physics: Energy and Culture

One concept from the physical sciences that attained cultural currency in all three areas – self, society, and the state – was energy. Although historians hitherto believed that the conservation of energy was an example of a mid-century cluster of discoveries concerning the conservation of force, Crosbie Smith has demonstrated that the central group in the articulation of the concept was found in northern British industrial culture and consisted of the brothers James and William Thomson, James Clerk Maxwell, and others. The concept of energy, linked via the new science of thermodynamics to ideas of work, waste, and (eventually) entropy (the dissipation of energy or the disorder of the universe), decisively shifted interpretations of physical reality away from the French deterministic one with its emphasis upon mechanics and reversibility toward one that understood reality in statistical terms and that posited the irreversibility of complex physical processes. In 1854 William Thomson coined the term "thermodynamics." Ongoing efforts at industrialization provided the cultural context for linking energy to economic concerns, especially the efficient production of power. Because no engine was perfectly efficient, practitioners not only separated the inefficient human world from the (apparently) efficient natural one, but also attributed inefficiencies in the human world to human imperfections, specifically to the lack of skill in the design of engines. Thus, the mere attempt to achieve efficiency was imbued with moral overtones as a step toward improvement, perfection, and the efficient use of resources, while inefficiencies and waste were associated with evil. The belief in irreversibility, furthermore, killed all belief in cyclical cosmologies and so endorsed the doctrine of a specific beginning to the age of the earth consistent with Christian views on time. Energy physics thus became a weapon against anti-Christian materialists and naturalists, but the complete dissipation of energy was believed to represent pessimistic fatalism inconsistent with Christian belief in redemption. Thermodynamics in the northern British experience thus meshed with cultures of industrialization and Presbyterianism through Whig, reforming, and progressive values, which in turn aided the cultural integration of energy into the quotidian.

Energy became a powerful concept for interpreting psychological, social, economic, and political realities. The division of gender activities into productive (male) and reproductive (female) spheres seemed especially illustrative of the conservation of energy and its calculus of input and output. Menstruation was thus viewed as depleting the woman's reservoir of energy, leaving her with less to invest in both physical and intellectual activities; hence her absence from the productive sphere and from intellectual life was merely the result of biological determinism. Anson Rabinbach has argued that the conservation of energy gave the idea of the "human motor" considerable credence given the central importance of human labor and the working class to industrializing Europe. The working body became one of the many devices that converted energy into work, just like the steam engine. With this image of the body as a source of productive energy in mind, liberal social reformers believed they could craft legislation that would efficiently channel that energy into productive enterprises. But such hopes of harnessing the labor power of the human machine could not overcome one of the persistent disorders of modernity – fatigue – as much a moral as a physical shortcoming, studied by scientists like Etienne-Jules Marey and Angelo Mosso in the laboratory between the 1870s and the 1890s. The socioeconomic problem of human productivity was thus subject to empirical research guided by rational principles in the hopes of producing a calculus of energy and fatigue. So pervasive was the belief in the conservation of energy that Sigmund Freud made it one of the foundations of the dynamics of the human mind: he thought of neuroses and abnormal behaviors as physical manifestations of an imbalance in psychical energies.[21]

Science and Modernity

The cumulative effect of science upon life at the end of the century by all accounts was regarded as ambiguous. Scientists like Rudolf Virchow praised the entry of science into daily life and its role in the rational upbringing of the population, but others regarded that infiltration as suspicious if not destructive of fundamental values. As psychologists everywhere knew, a general nervous temperament seemed to permeate society thanks to precision clocks accurate to one minute in the marketplace and train station, an electrified urban environment, and a pace of life that seemed out of control. National identity itself became a psychic phenomenon. Gestalt psychologists believed that science was incapable of dealing with the problems of daily life and so called for a new way of looking at objective reality. Appropriately, Friedrich Nietzsche – perhaps the harshest critic of progress as historical emplotment – astutely noted that modernity coincided with the collapse of classical theories of vision and that modern objectivity was simply a form of "bad taste."[22]

And yet such criticisms bred their own peculiar forms of optimism similar to what the German philosopher Georg Friedrich Hegel had found when he was among the first to criticize modernity at the beginning of the century. Hegel had been critical of Enlightenment rationality and the hardening of ideas in the disciplines, but he wanted a critical spirit, and identified one way of achieving it in the *Preface to the Phenomenology of the Mind* (1806). So did Nietzsche, who sought to replace the harsh daylight of the Enlightenment with a "twilight," to replace reason with the senses, and to replace science by art. Secularization accompanied modernity, to be sure, yet the issue was not one of a constant conflict with the Bible, but rather of finding substitutes for traditional religion. This search remained high on the list of priorities for scientists. Durkheim believed that a replacement for religion could be found in sociology, for it affirmed the importance of ethical norms in social life. Charcot, Freud's teacher, studied the Marian cult at Lourdes not only in an attempt to explain miraculous cures in rational terms, but also to understand why miracles worked only for those who believed in them. From there he hoped he would then be able to explain why psychiatry, like the miraculous, was effective only where there was belief in its powers.[23] Weber himself admitted that the historical process of rationalization could be countered by personal charisma, a liberal notion based on individual personality, creativity, and idiosyncrasy, all traits the disciplines had buried when they eliminated the possibility of genius. The interpretation of natural processes according to the principles of statistics and probability seemed to remove a purposeful deity from nature, but Albert Einstein, whose revolutionary theories of 1905 on spacetime, the photoelectric effect, and Brownian motion (the latter requiring a foundation in statistics), refused to believe that the universe was governed by chance.

Daily life continued to metamorphose as a result of developments in science and technology, and not everyone greeted the accompanying changes with disdain. A new global chronometric regime was instituted in 1884 with the meridian running through the Greenwich Observatory in Britain as the zero point of 24 equal time zones of 15° each. Aside from a single Russian anarchist immortalized in Joseph Conrad's novel *The Secret Agent* (1907), no one seems to have strongly objected to this universal standard time. Nor were there objections to universal standards for electrical units, established in 1881, which paved the way for the management of the electrical utilities that would power other new inventions such as the telephone, cinema, and radio. The notion of modernity as it took shape in the nineteenth century rested on the roles of science, technology, and reason in the historical process, especially in the unfolding of the Enlightenment promise of progress and emancipation through the application of reason. The turn-of-the-century sentiment against science and technology might itself be interpreted as the continued affirmation of the critical function of reason in the public sphere, a development in which science and scientific culture had played such large parts.

NOTES

1 Stichweh (1992).
2 Turner (1980: 119).
3 See Warwick (2003).
4 See Schaffer (1990).
5 See Taylor (1989); Olesko (1991).
6 See Cahan (1985); Kim (2002).
7 See Morrel and Thackray (1981); Nyhart and Broman (2002).
8 See Cantor et al. (2004).
9 See Cahan (1989).
10 See Russett (1989); Wetzell (2000); Goldstein (1987).
11 See Crary (1992).
12 Schivelbusch (1986).
13 See Crary (1999).
14 See Porter (1986).
15 See Golinski (1992).
16 See Schivelbusch (1988); Schlör (1998).
17 See Reid (1991); Evans (1987); Ladd (1990); Goubert (1989).

18 See Weindling (1989).
19 See Gugerli and Speich (2002).
20 See Adas (1989); Richards (1993); Prakash (1999).
21 See Rabinbach (1990).
22 See Radkau (1998); Ash (1995).
23 See Goldstein (1987).

GUIDE TO FURTHER READING

A lively introduction to the social history of knowledge and attendant practices in late eighteenth-century institutions ranging from the academy to the literary public sphere can be found in Peter Burke's well-written survey, *A Social History of Knowledge from Gutenberg to Diderot*. For an engrossing example of how one state harnessed science and technology as the new century began, see Ken Alder's story of the meter, a project carried out in the heady days after the French Revolution: *The Measure of All Things*. David Cahan's *From Natural Philosophy to the Sciences* is an assessment of the historiography on nineteenth-century science; it also identifies important new directions of research.

Many scientific concepts, including forms of scientific rationality, filtered into daily life. On how probability in the form of risk assessment became a part of everyday thinking, see Gigerenzer et al.'s *Empire of Chance*. Bureaucrats and other public officials clung to the "objectivity" of numbers when trust and power were in short supply, according to Theodore Porter in *Trust in Numbers*. Few scientific concepts entered common parlance as thoroughly as did energy and work; see Smith's *Science of Energy* and Rabinbach's provocative *Human Motor*. On how science and technology changed time-consciousness and the perception of time and space, see Kern's *Culture of Time and Space*. The final chapters in the revised edition of Benedict Anderson's *Imagined Communities* still offer provocative ways of thinking about national identity in terms of the artifacts of science and technology.

The cultural criticism of science, technology, and rationality and their roles in the construction of modernity are best approached through the original writings of major European intellectuals of the period, especially Karl Marx, Friedrich Nietzsche, Émile Durkheim, Sigmund Freud, and especially Max Weber.