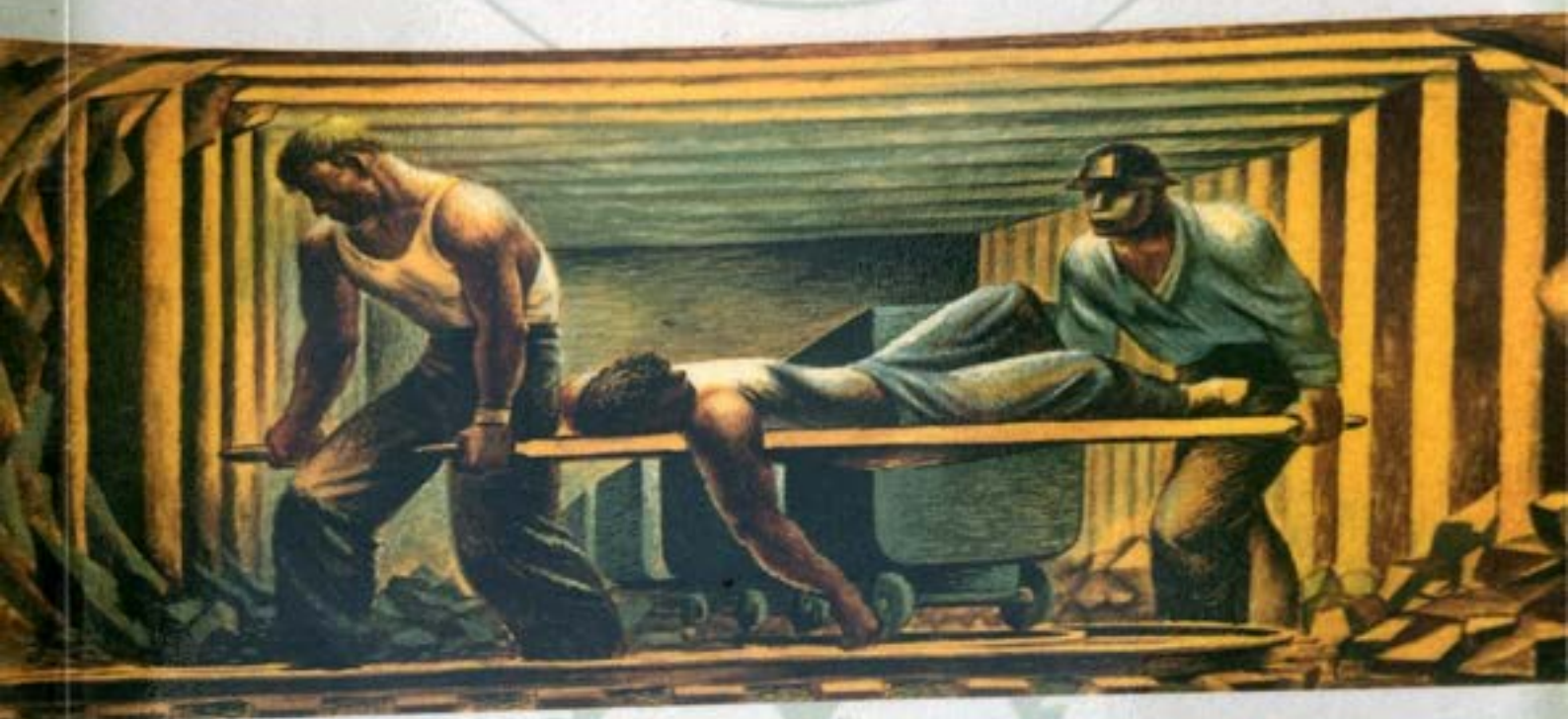


"A delightfully refreshing new look at the history of science."

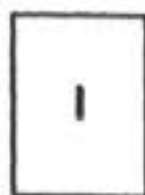
— HOWARD ZINN

A PEOPLE'S HISTORY OF SCIENCE



MINERS, MIDWIVES,
AND "LOW MECHANICKS"

CLIFFORD D. CONNER



WHAT SCIENCE? WHAT HISTORY? WHAT PEOPLE?

WE ALL KNOW the history of science that we learned from grade-school textbooks: how Galileo used his telescope to show that the earth was not the center of the universe; how Newton divined gravity from the falling apple; how Einstein unlocked the mysteries of time and space with a simple equation. This history is made up of long periods of ignorance and confusion, punctuated once an age by the "Eureka!" of a brilliant thinker who puts it all together. In this traditional heroic account, a few Great Men with Great Ideas tower over the rest of humanity, and it is to them that we owe science in its entirety.

The legend of Pythagoras exemplifies the seemingly timeless tendency to attribute all scientific creation to individual hero-savants. With regard to ancient Greek and Roman commentaries on their semimythical predecessor, Walter Burkert observed that "to a later age it seemed natural to retroject their own notion of 'wisdom' upon the great figures of the past and to impute to them that which from a modern point of view is 'science.'"¹ Unfortunately, that practice is still all too much in evidence today.

What I am presenting here, by contrast, is a *people's* history of science that aims to show how ordinary humans participated in creating science in profound ways. It is a history not only *of the people* but *for the people* as well; its intended audience is not confined

to professional scientists or historians of science but includes anyone with an interest in the origins of scientific knowledge. And because I have drawn on the collective efforts of many predecessors, it might not be far-fetched to say that in a sense it is also *by the people*.

My central aim is to demonstrate a much, much greater contribution to the production and propagation of scientific knowledge on the part of anonymous masses of humble people—the common people—than is generally recognized or acknowledged. Isaac Newton's ability to "see further" should not be attributed, as he claimed, to his sitting "on the shoulders of giants," but rather to his standing on the backs of untold thousands of illiterate artisans (among others).²

It would be absurd, of course, to claim that the formulation of quantum theory or the structure of DNA can be credited directly to artisans or peasants, but if modern science is likened to a skyscraper, then those twentieth-century triumphs are the sophisticated filigrees at its pinnacle that are supported by—and could not exist apart from—the massive foundation created by humble laborers. If science is understood in the fundamental sense of *knowledge of nature*, it should not be surprising to find that it originated with the people closest to nature: hunter-gatherers, peasant farmers, sailors, miners, blacksmiths, folk healers, and others forced by the conditions of their lives to wrest the means of their survival from an encounter with nature on a daily basis.

A few brief examples—all of which will be explained in detail in the chapters below—can illustrate this contention. Virtually every plant and animal species we eat today was domesticated by experimentation and de facto genetic engineering practiced by preliterate ancient peoples. We are infinitely more in debt to pre-Columbian Amerindians than to modern plant geneticists for the scientific knowledge underlying food production. Even in relatively recent times, when American plantation owners wanted to grow rice, they found themselves compelled to buy African slaves with knowledge of the ecology of rice plants.

Likewise, the science of medicine began with and continues to draw on knowledge of plants' therapeutic properties discovered by prehistoric peoples. Amerindians demonstrated to Europeans the efficacy of the bark of the cinchona tree in treating malaria, and an African slave named Onesimus introduced the practice of inoculation against smallpox to North America. Credit for the discovery of vaccination that usually goes to Dr. Edward Jenner belongs instead to a farmer named Benjamin Jesty. Furthermore, until the nineteenth century the advance of medical science owed more to semiliterate barber-surgeons, apothecaries, and "irregular" healers than to university-trained medical scholars, whose influence tended to retard the acquisition of new medical knowledge. It was a Swiss pig-gelder named Jakob Nufer who in the 1580s performed the first recorded cesarean section.

The geography and cartography of the Americas and the Pacific Ocean are founded on the knowledge of the native peoples. Captain John Smith acknowledged that his celebrated map of the Chesapeake Bay area "was had by information of the Savages," and Captain Cook's maps of the Pacific Islands were derived from information given to him by an indigenous navigator named Tupaia. Anonymous sailors and fishermen were the original source of scientific data regarding tides, ocean currents, and prevailing winds; when Benjamin Franklin produced the first chart of the Gulf Stream, he acknowledged that it was entirely based on what he had learned from "simple" whalers.

Chemistry, metallurgy, and the materials sciences in general originated in knowledge produced by ancient miners, smiths, and potters. Mathematics owes its existence and a great deal of its development to surveyors, merchants, clerk-accountants, and mechanics of many millennia. And finally, the empirical method that characterized the Scientific Revolution of the sixteenth and seventeenth centuries, as well as the mass of scientific data on which it built, emerged from the workshops of European artisans.

The "folk" wisdom and lore of early societies was not an inferior kind of knowledge about nature that later was simply

canceled out and replaced by more accurate scientific knowledge. Science as it exists today was *created out of* folk and artisanal sources; it became what it is by drawing heavily on those sources. Knowledge, philosopher of science Karl Popper maintained, has for the most part advanced through the modification of earlier knowledge.

It might be argued that the approach I have outlined here cannot produce a balanced account of the origins of modern science. But the historical record has long been severely unbalanced by the gentlemen's historians and by the nature of history's dependence on written documentation, with power relationships determining who did the writing. No history of science could be less balanced than the traditional romantic narratives of Newtons, Darwins, and Einsteins transforming the world by the force of their unique brainpower. I am deliberately "bending the stick in the other direction," searching for the voices of the voiceless and sifting the record for very scarce evidence. The purpose of the sifting, however, is not to salvage some peripheral aspects of the development of science, but to demonstrate how the scarce evidence illuminates the hidden core of that development.

A selective approach does not necessarily lead to an unbalanced conclusion. Although my focus is on the activities of anonymous, ordinary people, I do not believe I have overvalued their importance in the process of generating scientific knowledge. It is not my contention that the familiar Great Men of Science played no role or were unimportant, but that their achievements were predicated on prior contributions of artisans, merchants, midwives, and tillers of the soil—most of whom have never been thought of as great and many of whom were not men.

Attempts to integrate women fully into the traditional heroic narrative are ultimately unlikely to be satisfying, not because women have ever been genetically inferior to men in intellect but because of the social barriers that historically have denied women education and entrée into scientific professions.³ The contributions of women receive considerably more recognition in a people's history of science because women constitute half of the

people, but even here parity is elusive due to the traditional exclusion of women from many craft occupations. But if women did not have much input in the development of oceanography because few were seafarers, they made up for it in the medical sciences in their roles as local healers and midwives.

The contributions to the history of science made by socially subordinate and illiterate people have not left the paper trail that historians customarily depend on for evidence. Lynn White, for example, blames "the neglect which historians have lavished upon the rustic and his works and days" on the fact that the peasant "has seldom been literate":

Not only histories but documents in general were produced by social groups which took the peasant and his labours largely for granted. Therefore while our libraries groan with data on the ownership of land, there is an astonishing dearth of information about the various, and often changing, methods of cultivation which made the land worth owning.⁴

The heroes of the traditional story of eighteenth-century scientific agriculture are "improving landlords" such as Jethro Tull and Thomas "Turnip" Townshend, whose spirit of experimentation was allegedly the driving force behind the great leap forward. But as T. S. Ashton explained in his classic study of the Industrial Revolution, "Tull was a crank, and his importance in the history of agriculture has been vastly exaggerated." As for Viscount Townshend's role in the introduction of the turnip as a field crop, "recent research has shown that he was the popularizer, rather than the originator, of this." There was no single originator; it was a collective accomplishment. Agricultural experiments "were being made by obscure farmers in many parts of the country"; then, "knowledge of the new methods was spread at tenants' dinners, shearing feasts, and the more frequent meetings of many local farmers' clubs." On the larger manors it was not the wealthy landlords but their humble tenants whose hands were actually in the soil and the manure, experimenting with new crops and procedures. The new

agronomic knowledge, "like every major innovation, was the work of many hands and brains."⁵

The development of the peasants' knowledge that "made the land worth owning" is impossible to trace by archival research, and the same is true of much of the scientific knowledge produced by artisans who were unable to read and write. In recent decades, however, historians have begun to tap the methodology of anthropology and other disciplines to show that a great deal can be learned about the past—and not only the "prehistoric" past—without recourse to written sources. Furthermore, some assertions not supportable by documentation may be deemed valid due to the lack of any viable alternative explanation—for example, the proposition that anonymous sailors and fishermen were the original source of scientific data regarding ocean currents and prevailing winds.⁶

The chronological scope of this survey of scientific history is as vast as it could possibly be—from the Paleolithic to the postmodern—but it is markedly weighted toward a particular period: the fourteenth through seventeenth centuries of the Common Era, which encompass the origins of what has come to be known as *modern* science.⁷ The geographical scope is likewise unlimited but somewhat skewed toward the western end of the Eurasian landmass. My view of history is not Eurocentric, but because this subject is inextricably entangled with the European imperial conquest of the rest of the globe, it therefore demands a disproportionate amount of attention to activities that occurred in Europe.

WHAT PEOPLE?

WHO ARE *THE people* who are both subject and object of this people's history? Occupational categories—such as artisans, merchants, and so on—give a good first approximation, but how shall they be collectively identified? I prefer to avoid denominating them as *the lower classes* or *the inferior orders*, except in quotation marks indicating irony, because those designations reflect the point of view of the privileged few who have always defined

themselves as superior to everyone else. *Common people* and *ordinary people* are slightly pejorative but perhaps not too objectionable; *the masses*, *the working class*, and *the proletariat* are not intrinsically worthless terms, but they suffer from overuse and an unfortunate association with discredited ideology of the Stalinist period. *The social majority* is not an insulting term, but its class-neutrality renders it a bit bland.

The laboring classes, *the poor*, or any synonyms thereof are inadequate because they do not include all elements of *the people* of the eighteenth century or earlier. In particular, they leave merchants, master craftsmen, and other members of the incipient capitalist class out of account.⁸ In France in the era of the Great Revolution, *le peuple* was handily defined by a legal category: the Third Estate, which included everyone who was not a member of the clergy or the nobility. Perhaps *the subordinate* or *dominated classes*—though somewhat awkward expressions—best convey the social relationships that need to be indicated. *The crowd*? Maybe. *The mob*? Definitely not. *The many*? However defined, it is their interests that form the vantage point from which the origin and development of science are evaluated in this book.

As for who *the people* are not: Those who defined themselves as “upper class,” “noble,” and “persons of quality” were, by definition, superior in social power to those whom they excluded from those categories. But their self-designations also carry an implication of moral superiority that would strike a dissonant note in a people’s history. They can be adequately denominated, and their social position acknowledged, by such terms as *the dominant class*, *the ruling class*, *the privileged orders*, *the elite*, and so forth.

Very few of the traditional Heroes of Science were born into the ruling class per se. Some were indeed aristocrats or royals—Robert Boyle, Tycho Brahe, and Prince Henry “the Navigator” come quickly to mind—but most were co-opted into the circles of privilege as highly placed servants by means of university positions (Newton, Galileo) or other forms of patronage (Galileo, Bacon). “The educated elite,” historian of science William Eamon explains, “became a kind of intellectual

aristocracy."⁹ What defined members of the scientific elite, then, is not the blueness of their blood but their status as professional intellectuals.

A very sharply defined social barrier has always—at least since the origin of social differentiation in the misty dawn of prehistory—been based on the distinction between manual and intellectual work. People who work with their hands have long been looked down upon as inferiors by those who make their livings without getting their hands dirty. The class distinction between educated scribes and illiterate craftsmen in the earliest civilizations is clearly evident in the occupational guidance an ancient Egyptian father of about 1100 B.C.E. gave his son, to “give thy heart to letters” and thereby avoid manual labor. “I have seen the metal worker at his toil before a blazing furnace,” the father warned. “His fingers are like the hide of the crocodile, he stinks more than the eggs of fish. And every carpenter who works or chisels, has he any more rest than the ploughman?”¹⁰

In the ages of Plato and Francis Bacon, the disdain for manual labor was expressed openly and frequently by professional intellectuals (in imitation of their aristocratic patrons) and was given an extensive ideological foundation. “The arts which we call mechanical,” says Xenophon, a contemporary of Plato’s, are “generally held in bad repute.” Furthermore:

States also have a very low opinion of them—and with justice. For they are injurious to the bodily health of workmen and overseers, in that they compel them to be seated and indoors, and in some cases also all the day before a fire. And when the body grows effeminate, the mind also becomes weaker and weaker. And the mechanical arts, as they are called, will not let men unite with them care for friends and State, so that men engaged in them must ever appear to be both bad friends and poor defenders of their country. And there are States, but more particularly such as are most famous in war, in which not a single citizen is allowed to engage in mechanical arts.¹¹

This was an attitude with staying power. "Scholastic depreciation of 'rustics' and 'the crowd' became particularly virulent in the thirteenth century," Eamon reported, "as the educated elite attempted to reinforce its status and to set itself above the herd of ordinary men."¹² The distinction is less commented on today in societies that lay claim to democratic values, but no one, I think, could credibly deny its continued existence.¹³

In addition to taking pride in never soiling their hands through labor, another mark of the scientific elite during the period of the rise of modern science was "literacy," which in early modern Europe meant not merely knowing how to read and write, but being able to do so in Latin. "Knowledge of the Latin language" was "the skill that alone distinguished the learned from the vulgar, the elite from the popular."¹⁴

Yet another of the primary characteristics of the subjects of this people's history is anonymity. The names of many university-trained scholars who earned a place in scientific history are immortalized by their published writings, but the names of most illiterate and semiliterate artisans are usually recorded, if at all, only in birth, baptismal, marriage, and death records that give no clue as to their role in the creation of natural knowledge.

There are, however, notable exceptions. Some artisans wrote in the vernacular and published manuals and "books of secrets" under their own names.¹⁵ At least two tradesmen have even been treated on occasion as bona fide Great Men of Science: John Harrison, for solving the most pressing scientific puzzle of his age, how to measure longitude at sea;¹⁶ and Antony van Leeuwenhoek, the "father of protozoology and bacteriology."¹⁷ Many artists and architects who contributed to the history of science—the Michaelangelos, the Leonardos, the Brunelleschis—attained great fame and aristocratic patronage, but they were essentially craftsmen nonetheless—"superior manual laborers," as Edgar Zilsel called them.¹⁸ There is also one prominent figure whose battles against the scientific elite arguably qualify him as a "people's scientist": Theophrastus Bombastus von Hohenheim, better known as Paracelsus. But despite the exceptions, it remains the rule that the names of most of those whose contributions form the

subject of this book are lost to history. In any event, the main concern of a people's history is the scientific accomplishments not of individuals but of occupational groups.

While acknowledging that some individuals defy categorization, it is useful to recognize working with hands, anonymity, not writing in Latin, and lack of patronage as identifying features that separate the social majority from the elite scholars. In the second half of the seventeenth century, science took its first significant steps toward professionalization, a process that continued over the following three centuries until it reached the point where virtually all scientific activities were being carried out by professional scientists. As the difficulty of attaining new knowledge about nature increased, only well-funded government- and corporate-sponsored research teams could afford to pursue it.

By the twentieth century, science had become the exclusive domain of highly specialized elites. The last two chapters of this book examine the rise of Big Science and consider whether the era when people without Ph.Ds were able to make direct contributions to science has come to a definitive end.

WHAT SCIENCE?

THE MEANING OF *science* is not as simple to pin down as might first be thought. The Latin *scientia* was a generic term encompassing all forms of knowledge, but in recent centuries *science* has come to include only certain kinds of technical knowledge. A few years ago the British journal *Nature* described the systematic efforts of a number of scientists to codify the meaning of the word in some precise way that would make it possible clearly to distinguish science from pseudoscience, but they were unable to produce a satisfying definition.¹⁹ I have followed the example set by J. D. Bernal's masterful *Science in History*, which he began by saying, "Science throughout is taken in a very broad sense and nowhere do I attempt to cramp it into a definition." This nondogmatic approach is necessary because

in the last resort it is the people who are the ultimate judges of the meaning and value of science. Where science has been kept a mystery in the hands of a selected few, it is inevitably linked with the interests of the ruling classes and is cut off from the understanding and inspiration that arise from the needs and capacities of the people.²⁰

At the very least science must be recognized as both a body of knowledge and a process of obtaining that knowledge. Let us, therefore, take the most uncomplicated approach possible and for the purposes of this book simply consider science to be *knowledge about nature* and the associated *knowledge-producing activities*. *

As for the kinds of activities that produce scientific knowledge, the primary focus in this book is on *empirical* as opposed to *theoretical* processes. It is my contention that the foundations of scientific knowledge owe far more to experiment and "hands-on" trial-and-error procedures than to abstract thought. Benjamin Farrington made the point very well:

In its origin science is not in fact so divorced from practical ends as histories have sometimes made out. Textbooks, right down from Greek times, have tended to obscure the empirical element in the growth of knowledge by their ambition of presenting their subjects in a logical orderly development. This is, perhaps, the best method of exposition; the mistake is to confuse it with a record of the genesis of theory. Behind Euclid's definition of a straight line as "one that lies evenly between the points on it" one divines the mason with his level.²¹

This is a broad, inclusionary concept of science that may not be palatable to readers conditioned to think of science in positivistic ways, with physics as the paradigmatic science against which all other fields are measured.²² Theoretical physicists have frequently belittled such disciplines as botany and paleontology by likening their intellectual content to that of stamp collecting.²³ The implication of that condescending slur is that physics is "more scientific" than are less

theory-driven disciplines—a reflection, once again, of the ancient prejudice that proclaims intellectual labor more honorable than manual labor. But what physicists do is not typical of what most other scientists do. The methodologies of biology, anthropology, ecology, psychology, and sociology have very little in common with the abstractions of theoretical physics, and yet the general ideology of modern science places physics on a pedestal as the model science which all other sciences should strive to emulate.

The “imperialism of physics”²⁴ was in no small part the creation of American governmental policy. Because of their role in developing the atomic bomb, a few “aristocrats of physics” emerged in the post-World War II period as the primary spokesmen for American science. It was they

who implanted their values, including disdain for the social and behavioral sciences, on government science policy for decades. The social and behavioral sciences were . . . arrogantly dismissed as the “soft sciences” by the reigning physicists of postwar science (who regarded themselves, along with chemists, mathematicians, and biologists, as practitioners of the “hard sciences”).²⁵

Giving physics a privileged place among the sciences reinforces the idea that science must be “value-free,” especially with respect to social problems.²⁶ In physics, the ideal of objectivity is equated with neutrality; by that definition, scientists are expected to be neutral and dispassionate with regard to the subject of their inquiry. Neutrality may be a workable stance for physicists to adopt, but in sciences that are closer to social concerns—such as medicine, anthropology, psychology, sociology, and political economy—the appeal to neutrality operates in support of the status quo, which is underpinned by racist, sexist, or bourgeois assumptions of which the scientists themselves are often unaware.²⁷ In recent decades, for example, the feminist movement has exposed a strong antifemale bias embedded in the traditional wisdom of elite medical science, which has for

millennia been highly detrimental to the health of women. That the medical profession long considered being female a pathological condition per se is reflected in the word "hysteria," which derives from the Greek for "uterus."²⁸

A people's history of science obviously cannot be constrained by the narrow *physics über alles* concept of science; equal status herein is accorded to all fields of natural knowledge, and no invidious comparisons of "hard" and "soft" or "exact" and "inexact" sciences are entertained. The concept of value-free science and its rise to a dominant position in the ideology of modern science have a history of their own that is further considered in chapter 6.

To challenge, as I do, the notion that science should be restricted to theoretical endeavors is to take sides in the "science wars" that have been roiling intellectual circles for a number of years. The traditionalists who portray science as "pure theory" do so in order to place it beyond criticism. That view of science is frequently an adjunct to reactionary political views because it supposedly offers a source of unchallengeable authority, like religion, and thereby serves as a support for authoritarianism. But many open-minded scholars, radical feminists, and environmental activists reject that notion and refuse to bow down before a deified Science.

SCIENCE AND TECHNOLOGY

ANOTHER IDEOLOGICAL COROLLARY of the intellectuals' contempt for manual labor is the "remarkably widespread wrong idea" that science is rigidly distinct from and supersedes technology in historical importance.²⁹ Our twenty-first-century perspective prompts us to think of technology as "applied science," a notion based on the facile assumption that scientific theory has always been a precondition of technological advance. Historically the opposite has most often been true: Although technology and science have always been closely associated endeavors, it is technology that has driven the growth of scientific knowledge.³⁰ The beginning of science, to paraphrase

Goethe, was not the *word* but the *deed*—not the proclamations of brilliant theorists but the creative handiwork of ordinary people. As technologies develop and become more sophisticated, the scientific knowledge generated at earlier stages is continuously incorporated into subsequent practice, and in that sense technology can indeed be said to exhibit the character of “applied science.” The relation is one of cumulative mutual reinforcement, with the initial impulses coming from the technology side.

Until the last century or two, the process of gaining knowledge of nature has generally been more a product of hands than brains; that is, of empirical trial-and-error procedures rather than theoretical application. “Science,” archaeologist V. Gordon Childe declared, “originated in, and was at first identical with, the practical crafts.”³¹ Social anthropologist Claude Lévi-Strauss dismissed the notion that any of the “great arts of civilization”—pottery, weaving, metallurgy, agriculture, and the domestication of animals—could have come about as a “fortuitous accumulation of a series of chance discoveries.” They provide evidence, he argued, that “Neolithic man” was “the heir of a long scientific tradition”:

Each of these techniques assumes centuries of active and methodical observation, of bold hypotheses tested by means of endlessly repeated experiments. . . . There is no doubt that all these achievements required a genuinely scientific attitude, sustained and watchful interest and a desire for knowledge for its own sake. For only a small proportion of observations and experiments (which must be assumed to have been primarily inspired by a desire for knowledge) could have yielded practical and immediately useful results.³²

“The crafts first uncovered aspects of nature upon which philosophies were later to be built,” and they remained the primary fount of nature-knowledge through the ages.³³ Science progressed in the early modern era—that is, from about 1450 through 1750—through analysis of the inventions and innova-

tions produced by artisans, many of whom were illiterate. In the Scientific Revolution of the sixteenth and seventeenth centuries, practical advances came first and theory followed along behind—usually far behind. This relationship persisted through the Industrial Revolution of the late eighteenth century. Not until well into the nineteenth century, with the mass production of chemical dyes and the advent of the electrical industry, were the long-anticipated hopes of major technologies based on theoretical science finally realized.³⁴ And even in the twentieth century, artisans were still capable of momentous scientific contributions. In 1903—the era of relativity and quantum theory—it was not theoretical physicists but two bicycle mechanics named Wright who gave the critical impulse to the science of aerodynamics. It was only with World War II and the Manhattan Project that theory began generally to lead the way in scientific discovery.³⁵

Rigidly separating the histories of science and technology serves to reinforce the fallacious notion that science arose from the realm of pure thought, floating in the clouds above the world of mundane human pursuits. An undistorted picture of the development of modern science requires recognition and acceptance of its entwinement with technology, often to the point of their not being recognizable as distinct entities.

Consider again, for example, the practice of navigation, which is generally classified as a technology and thought of as more art than science. It may seem odd to call a ship's pilot's activities scientific, but the historical progress of navigation depended entirely on the growth of an underlying body of nature-knowledge: of the oceans' tides, currents, and prevailing winds; of the characteristics of the earth's magnetic field; and of astronomical phenomena. Pioneering navigators in every age and in every part of the globe, as they sailed far from the sight of land, laid the foundations of hydrography and made essential contributions to the scientific disciplines of oceanography, meteorology, physical geography, cartography, and astronomy, among others.

Richard Westfall, a prominent historian of science, downplayed

the contributions made by ordinary seamen to the nautical sciences, contending that it was "never the practical tarpaulins who sailed before the mast, but always the astronomers and mathematicians, who taught the navigators."³⁶ Although it cannot be denied that professional mathematicians eventually contributed to the improvement of navigational practice, in the beginning the land-bound scholars were dependent on data supplied to them by mariners, as is amply demonstrated in chapter 4.

The work of mathematicians depended in an even more fundamental way on the prior activities of seafaring craftsmen. It was a specific need of navigators for simplified computational methods that stimulated John Napier's invention of logarithms, and it was the problem of finding a method of determining longitude at sea that led Isaac Newton to his formulation of the law of universal gravitation.³⁷ These important scientific advances were not driven primarily by the idle curiosity of isolated thinkers; they illustrate the collective, social nature of knowledge creation. It is not mere coincidence that Napier's and Newton's inspirations occurred in an island nation in an era of rapidly growing oceanic trade. In these cases, it was sailors who constituted the active element by posing the technical problems that elicited the mathematicians' responses. The universality of this relationship is evidenced by the first-century geographer Strabo's report that the Phoenicians, who were "superior to all peoples of all times" in seamanship, were "philosophers in the sciences of astronomy and arithmetic, having begun their studies with practical calculations and with night-sailings."³⁸

The counterposition of "mathematicians and astronomers" to "practical tarpaulins" depends on another hidden elitist assumption: that mathematical endeavors were the exclusive province of ivory-tower theoreticians. But that ignores the surveyors, mapmakers, instrument makers, navigators, and mechanics whose activities represented the leading edge, in the fifteenth and sixteenth centuries, of innovation in practical mathematics. The English mathematician John Wallis observed in his autobiography that "Mathematicks" even as late as the

1630s "were scarce looked upon as *Accademical* studies, but rather *Mechanical*; as the business of *Traders, Merchants, Seamen, Carpenters, Surveyors of Lands*, or the like."³⁹

The historical priority of technology over theoretical science is most generally exemplified by the central theme of this book, which is that *artisans contributed not only the mass of empirical knowledge that furnished the raw material of the Scientific Revolution, but the empirical method itself*. The science of the preceding era had been based almost entirely on the authority of ancient authors, Aristotle above all. In university and other elite settings, questions of natural knowledge were investigated by looking for answers in books or—in the rare instances when ancient authorities were challenged—by abstract *a priori* reasoning, not by directly interrogating nature. The habit of experimentalism that came to characterize modern science was a product of the craftsmen's shops, as is demonstrated in chapter 5.

WHAT HISTORY?

HISTORIANS IN GENERAL have succeeded in displacing the encomiastic tradition—the Great Man Theory of History—as the predominant viewpoint of the educated reading public, but historians of science—in spite of a great deal of effort and good scholarship—have been less successful. "Science," Derek de Solla Price lamented, "seems tied to its heroes more closely than any other branch of learning."⁴⁰ Although few people today would agree with Carlyle's famous dictum that "the history of the world is but the biography of great men," many continue to believe that the Scientific Revolution was the creation of a very few extremely talented geniuses: "from Copernicus to Newton."

Part of the problem is that although the public understanding of history in general has been strongly influenced by professional historians, the way most people conceive of the history of science has been shaped not by historians of science but by scientists themselves, who often hold and propagate distorted conceptions of their predecessors' practices.⁴¹ Scientists have a guild interest in portraying their forerunners as heroes, because

it adds to the heroic stature of their profession and enhances their view of their own place in the scheme of things.

More important, most scientists are not professional historians; their primary concerns are not historical. Their interest in their science's path of development is secondary to their interest in the science itself. They therefore often unwittingly adopt a tunnel-vision view of their discipline's past, focusing only on the narrow lineage of successes and ignoring all the false starts and dead ends as uninteresting because they did not "lead anywhere." Tunnel-vision history of science may be of some use as a teaching tool in elementary science courses, but it does not constitute valid history. Its projection of present-day concerns onto the past gives a falsified and misleading picture of the way science has developed in real life.⁴²

Some very capable historians of science have labored mightily in recent decades to overcome the idealized picture produced by scientists and by their own predecessors.⁴³ The scholarship of the best of the new generation of historians has provided the basis for this book, as the notes and bibliography attest. But, unfortunately, the academic field of history of science continues to concentrate most of its attention on a few scientific luminaries—a symptom, perhaps, of the cult of celebrity that afflicts our culture as a whole. The bulk of its books and articles are products of a "Galileo industry," a "Newton industry," a "Darwin industry," an "Einstein industry," and so forth.⁴⁴ The Great Men of Science, like the proverbial elephant in the parlor, cannot be ignored. But their stories have traditionally been told from the perspective of the ruling elites; I reexamine them from a different point of view.

SOCIAL HISTORY AND PEOPLE'S HISTORY

WHAT DISTINGUISHES A "people's history" from the more general category of social history? They are overlapping but not identical approaches to understanding the past. Social historians have done an admirable job of describing the social context in which the traditional Heroes of Science worked. Explaining

Boyle's and Newton's activities in light of the English Civil Wars and the Glorious Revolution, for example, is a valuable corrective to idealized history of science.⁴⁵ A people's history, however, aims at deepening the understanding of science as a social activity by emphasizing the collective nature of the production of scientific knowledge.

Social historians for many years now have been presenting their pictures of the past from "the bottom up" rather than from "the top down." Some have described the activities of the common people or have in other ways broadened the social context in which historic events have been understood, but without abandoning the point of view of the dominant social classes.

Also, some social historians have purposefully directed their attention toward the privileged classes. Steven Shapin's *A Social History of Truth* is an excellent example of social history of science, but his account of what he calls "the gentlemanly constitution of scientific truth" in seventeenth-century England is explicitly grounded in an elite perspective. "I am both well aware of, and deeply sympathetic towards, the new cultural history of the disenfranchised and the voiceless," Shapin wrote. "To the extent that I focus on the society of gentlemen," however, "this is a story told 'from their point of view.'"⁴⁶

Shapin's focus was on the role of seventeenth-century gentlemen in the production of scientific knowledge. That role was essentially an epistemological one—that is, the certification or legitimation of knowledge. The question Shapin examined is not how gentlemen came to know new things about nature, but how they came to agree among themselves that they knew those things. Those who were actually making new discoveries about nature were artisans—people who worked with hands as well as brains and who were motivated not primarily by curiosity but by material necessity: the need to make a living. In a nutshell, the birth of modern science occurred when gentlemen began to appropriate artisans' knowledge and to systematize it. This theme is developed more fully in chapter 5.

Artisans, it should be noted, needed no formal means of

legitimizing what they knew and were generally unconcerned with whether others agreed with it. Their knowledge of nature was tested, confirmed, and continuously reconfirmed in their daily practice. If what they knew "worked" for them, that was legitimacy aplenty. Robert Boyle observed that empirical data discovered by artisans, "if they really serve the craftsman's turn, must be true" and are therefore "fit to be admitted into the history of nature."⁴⁷ Sailors and fishermen once again provide a cogent example. Their precise knowledge of the relation between the moon's position and the tides, which they recorded in accurate tables, had helped them safely reach port for many centuries before Galileo erroneously denied the moon's agency and instead attributed the tides to the earth's rotation.⁴⁸

While acknowledging that his book is about "a small group of powerful and vocal actors," Shapin challenged other historians to look in other social directions as well: "If there are past voices—of women, of servants, of savages—in the practice to be attended to and made audible, then there is every reason why historians should, if they choose, concern themselves with them." On the other hand, he added, "if there are no such voices, or if they are almost inaudible," then historians should pay attention to the *"practices of inclusion and exclusion"* through which some speak and others are spoken for, and some act and others are acted upon."⁴⁹

I have attempted to heed Shapin's advice. Although there are some faint voices of knowledge-seeking members of the subordinate classes that can be amplified and made audible, an alternative approach to uncovering their place in the history of science is to analyze carefully the words and deeds of those who "spoke for" and "acted upon" them. It is by the testimony of Bacon and Boyle, of Gilbert and Galileo, that a strong case for the significance of the "illiterate mechanicks" can be made.

WHOSE KNOWLEDGE WAS IT, ANYWAY?

ALMOST ALL AUTHORS who have commented on the subject of craft secrecy have condemned it and deplored the backwardness

of benighted craftsmen who attempted to hoard their knowledge, while praising elite *virtuosi* such as Robert Boyle for making new knowledge about nature public. Those who freely shared the results of their investigations by publishing them have been hailed almost universally for their unselfish contributions to human enlightenment and progress. That, of course, is the light in which Boyle, Bacon, and their like-minded colleagues saw themselves, and most subsequent authors simply echoed their point of view, perhaps without thinking about it very deeply. But although Baconian propaganda claims "mankind" in general as its concern and the "bettering of man's life" as its motive, Bacon's own program for progress clearly included maintaining and strengthening the social status quo—to increase the power of the dominant elite over the popular masses.⁵⁰

Artisans saw the practice of craft secrecy in quite a different light. It was not motivated by evil intent on their part; they looked on it as a necessary condition for their economic survival: "Technical knowledge was the craftsman's most valuable property, even more valuable than his materials or his labor."⁵¹ Their knowledge of natural processes had been gained by hard work and years of apprenticeship; it was the source of their income, the basis of their ability to make a living and support themselves and their families. When well-off gentlemen who could afford to be magnanimous exposed the lore of the craftsmen to public view, it was, from the standpoint of the artisans' interests, an act of robbery.

The *virtuosi's* posture as champions of the free exchange of scientific ideas may seem warranted because they did not hoard the stolen knowledge for themselves but broadcast it to the world. But their liberality mirrored the hypocrisy of laissez-faire economics; those countries that are the staunchest advocates of free markets are invariably those most able to dominate them: Great Britain in the nineteenth century and the United States today. In the "marketplace of ideas," the intellectual elite was likewise in a position to control the valuable knowledge it "liberated."

Robert Boyle attempted to justify appropriating the

craftsmen's knowledge by arguing that it would be repaid eventually with interest: "as the naturalist may . . . derive much knowledge from an inspection into the trades, so by virtue of the knowledge thus acquired . . . he may be as able to contribute to the improvement of the trades."⁵² There is no reason to doubt Boyle's sincerity in assuming that "improvement of the trades" would result in bettering the tradesman's condition, but that was not what happened. In the context of a nascent capitalist economy, the benefits of increased productivity went not to the producers but to a privileged few whose access to capital allowed them to gain control of the productive process. The artisans who forfeited their knowledge were for the most part eventually forced into dependency as wageworkers. Boyle's "improvement of the trades" was a forerunner of the nineteenth-century introduction of so-called labor-saving machinery, which did not serve to ease the labor of the laborers but to reduce the *labor costs* of their employers. No matter how socially progressive it may have been in the long run, the immediate effect was that displaced workers lost their livelihoods while factory owners enriched themselves.

The general themes and arguments of this book should by now be sufficiently clear. It is time, then, to back up and begin our examination of people's science at the beginning—with the earliest people: the hunter-gatherers in all parts of the globe.



NOTES

1. Walter Burkert, *Lore and Science in Ancient Pythagoreanism*, p. 217. The case of Pythagoras is discussed further in chapter 3.
2. If ever a final word has been written on any subject, surely it is Robert Merton's *On the Shoulders of Giants* ("OTSOG" for short) with regard to the famous aphorism commonly attributed to Newton. Newton used it in a letter to Robert Hooke, February 5, 1675/76 (Newton, *Correspondence*, vol. 1, p. 416).
3. Margaret Rossiter has made this point particularly well. See her *Women Scientists in America*.

4. Lynn White Jr., *Medieval Technology and Social Change*, p. 39.
5. T. S. Ashton, *The Industrial Revolution, 1760-1830*, p. 27-28, 62.
6. The contributions of seamen are explored more fully in chapter 4.
7. In this book the abbreviations "C.E." and "B.C.E.," for "Common Era" and "Before the Common Era" are used instead of "A.D." and "B.C.," respectively.
8. The status of the better-off members of the incipient capitalist class as an urban elite was relative; in the context of aristocratic society as a whole, they were a "subelite," or "middle," class.
9. William Eamon, *Science and the Secrets of Nature*, p. 80.
10. *Egyptian Hieratic Papyri in the British Museum*, second series (London, 1923); quoted by J. D. Bernal, *Science in History*, vol. 1, p. 130.
11. Xenophon, *The Economist*, chapter 4, pp. 22-23.
12. Eamon, *Science and the Secrets of Nature*, p. 80.
13. "The millennial separation of . . . thinker from craftsman," a leading historian of technology comments, "is not vanished even in our own time." Lynn White, Jr., "Pumps and Pendula," p. 110.
14. Eamon, *Science and the Secrets of Nature*, p. 37.
15. "In the late Middle Ages," Eamon wrote, "as literacy spread, craftsmen began more frequently to record their technical secrets in writing. They composed handbooks to train other artisans and to stake claims to their inventions." He cited "dozens of examples." Eamon, *Science and the Secrets of Nature*, p. 83. This artisanal literature is discussed further in chapter 5.
16. A book, Dava Sobel's *Longitude*, and a four-hour television documentary based on that book attempt to win entry for Harrison into the pantheon of great scientists.
17. Clifford Dobell, ed., *Antony van Leeuwenhoek and His "Little Animals."* The quoted phrase appears on the cover of the book.
18. See, e.g., Edgar Zilsel, "The Origins of Gilbert's Scientific Method," p. 91.
19. "Physicists Seek Definition of 'Science,'" *Nature*, April 30, 1998.
20. J. D. Bernal, *Science in History*, vol. 1, pp. 3, 34. The author of this important four-volume study of the history of science was not primarily a historian. J. D. Bernal's contributions to the science of crystallography place him among the leading twentieth-century physicists.
21. Benjamin Farrington, *Science in Antiquity*, p. 3.
22. On the other hand, some historians of science may find this definition of science not inclusionary enough, on the grounds that it begs the question of exactly what is meant by "knowledge." Does it include all of what people of the past considered to be knowledge, or is it restricted to what we today, with benefit of hindsight, accept as knowledge? (See, e.g., the introductory essays in Michael H. Shank, ed., *The Scientific Enterprise in Antiquity and the Middle Ages*.) Although I agree that retrospectively discredited knowledge should not be excluded from the history of science, in this book the emphasis is on the origins of knowledge that most readers would accept as still valid today.

23. The "stamp-collecting" insult originated a century ago with the physicist Ernest Rutherford, but it has been repeated many times since.
24. I have borrowed this phrase from Richard Creath, "The Unity of Science," p. 168.
25. Daniel S. Greenberg, *Science, Money, and Politics*, pp. 451-453.
26. Feminist philosophers of science have been among the most insightful critics of the notion of "value-free" science. See Sandra Harding, *The Science Question in Feminism*, pp. 43-44, 227-228, 232-233; Helen Longino, "Can There Be a Feminist Science?" and Helen Longino, *Science as Social Knowledge*, chapters 4 and 5.
27. Harding, *The Science Question in Feminism*, p. 47.
28. See the section "Feminism versus Medical Science" in chapter 8.
29. Derek J. de Solla Price, "Of Scaling Wax and String," p. 239.
30. Jacques Barzun distinguished between the practical arts, *techne*, and "their familiar term *technology*." Barzun, *From Dawn to Decadence*, p. 205. I stick with the more
31. V. Gordon Childe, *Man Makes Himself*, p. 171.
32. Claude Lévi-Strauss, *The Savage Mind*, pp. 13-15.
33. Cyril Stanley Smith, "Preface" to Denise Schmandt-Besserat, ed., *Early Technologies*, p. 4.
34. On mass-produced chemical dyes as the first significant science-based technology, see David Landes, *The Unbound Prometheus*, pp. 274-276.
35. Ironically, the best presentation of the case for the ontological priority of technology over (theoretical) science I have encountered was made by authors who would, I strongly suspect, reject my definition of science: James McClellan and Harold Dorn, *Science and Technology in World History*. In my view, their definitions minimize the empirical side of science and focus only on the theoretical side. In so doing, they draw an unreasonably sharp line between technology and science, which led them to conclude that "science and technology followed separate trajectories during 2,000 millennia of prehistory" (p. 5). Harold Dorn, *The Geography of Science*, argued even more forcefully against "conflating technology and science" (pp. 17-21). Nonetheless, McClellan and Dorn did an excellent job of demonstrating that technology was the ground from which science grew, and that is the main point I am trying to make here.
36. Richard Westfall, "Science and Technology during the Scientific Revolution," p. 69. Westfall was echoing the sentiments of John Flamsteed (1646-1719), England's first royal astronomer, who wrote: "All our great attainments in science . . . have come . . . from the fire-sides of thinking men . . . and not from Tarpawlins, tho' of never so great experience." Quoted in E. G. R. Taylor, *The Mathematical Practitioners of Tudor and Stuart England*, p. 4.
37. See the section "Isaac Newton and the Hessen Thesis" in chapter 6.

38. Strabo, *The Geography of Strabo*, vol. VII, p. 269.
39. Christoph J. Scriba, ed., "The Autobiography of John Wallis, F.R.S.," p. 27 (emphasis in original).
40. Derek J. de Solla Price, *Science since Babylon*, p. 47.
41. "Leaders of science," Daniel Greenberg observed, "are not the most reliable commentators on the historical, political, and financial realities of their profession." Greenberg, *Science, Money, and Politics*, p. 77.
42. To avoid being charged with hypocrisy, I must again acknowledge that this book is not entirely free of the tunnel-vision syndrome. (See note 22 above.) My defense is that this is a brief survey of a very large subject, not intended to be comprehensive, focusing on continuities of knowledge that will be recognizable to nonspecialists in the history of science.
43. Alexander Koyré and A. Rupert Hall were among the most influential idealizers of the history of science. See chapter 5. As for the "very capable historians of science," I have identified a representative sample in the acknowledgments to this book.
44. See Mott T. Greene, "History of Geology," p. 97.
45. See James Jacob, *Robert Boyle and the English Revolution*; and Margaret Jacob, *The Newtonians and the English Revolution, 1689-1720*.
46. Steven Shapin, *A Social History of Truth*, p. xxi.
47. Robert Boyle, *That the Goods of Mankind May Be Much Increased by the Naturalist's Insight into Trades*, p. 444.
48. See the section "The Tides" in chapter 4.
49. Shapin, *Social History of Truth*, p. xxii (emphasis in original).
50. See the epigraph to chapter 6. Bacon's ideas regarding the social uses of science are discussed further in that chapter.
51. Eamon, *Science and the Secrets of Nature*, p. 81.
52. Boyle, *That the Goods of Mankind May Be Much Increased by the Naturalist's Insight into Trades*, p. 446.