Science and Technology in World History

AN INTRODUCTION

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THE JOHNS HOPKINS UNIVERSITY PRESS
Baltimore and London

 Published 1999
Printed in the United States of America on acid-free paper
9 8 7 6 5 4 3 2 1

The Johns Hopkins University Press
2715 North Charles Street
Baltimore, Maryland 21218-4363
www.press.jhu.edu

Library of Congress Cataloging-in-Publication Data will be found at the end of this book.

A catalog record for this book is available from the British Library.

ISBN 0-8018-5868-2
ISBN 0-8018-5869-0 (pbk.)

Preface and Acknowledgments

This book was written as an introduction for lay readers and undergraduate students to provide the "big picture" that an educated person might wish to have of the history of science and technology. It was not written for scholars or experts, and its character as a textbook is self-evident. The presentation grows out of our extensive experience of engaging undergraduates in these matters. The hard knocks of the classroom have suggested both the essential lessons and what materials and examples work well in conveying those lessons.

We owe thanks to valued friends on whom we imposed to read portions or all of the manuscript and whose critical comments substantially improved the final effort; in this connection we cannot omit mention of Dr. Philip R. Reilly, Prof. James E. McClellan Jr., Jackie McClellan, and Messrs. Michael Feldstein, Paul Kay, and Jeff Ruth. Similarly, we are indebted to a number of professional colleagues whose specialized expertise saved us from more than one gaff, and here we must name Professors Mott T. Green and James Evans of the University of Puget Sound, Dr. Murray C. McClellan of Boston University, Dr. Deepak Kumar of NISTADS in New Delhi, and two anonymous reviewers.

Dr. Robert J. Brugger of the Johns Hopkins University Press started us down this rocky road, and his substantive and stylistic suggestions along the way resulted in many improvements. Others at the Press displayed outstanding professionalism in addition to a welcomed tolerance toward a cantankerous authorial couple, and we have especially to thank Kimberly F. Johnson, Lee Campbell Sioles, Anita Walker Scott, and Therese D. Boyd for their several contributions.

The people and resources at the New York Public Library, the American Museum of Natural History, and the libraries of Columbia University were instrumental in helping us locate essential scholarly and iconographic materials, for which we express our sincere appreciation. Ms. Carol Perkins and the staff of Williams Library at Stevens Institute of Technology likewise proved invaluable as well as unusually efficient in negotiating interlibrary loans for us, and we have the pleasure of acknowledging their many kindnesses again in print. Our friends at Modernage Photographic Services on Sixth Avenue in Manhattan did their usual high-quality thing and made this a more appealing book than it otherwise would have been. Mr. Shyam Laxminarayan helped us in checking Web resources. Mr. William L. Nelson drew the maps; Dr. Andrew P. Rubenfeld prepared the index.

And finally, we thank our students at Stevens Institute of Technology who tested drafts of this book: they let us know when we succeeded in communicating the story clearly and when we did not. What follows is not error free, and we alone are responsible for its shortcomings.

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The Guiding Themes

The twentieth century has witnessed a fateful change in the relationship between science and society. In World War I scientists were conscripted and died in the trenches; in World War II they were exempted as national treasures and committed to secrecy, and they rallied behind the war effort. The explanation of the change is not hard to find—governments came to believe that theoretical research can produce practical improvements in industry, agriculture, and medicine. That belief was firmly reinforced by developments such as the discovery of antibiotics and the application of nuclear physics to the production of atomic weapons. Science has become so identified with practical benefits that the dependence of technology on science is commonly assumed to be a timeless relationship and a single enterprise. Science and technology, research and development—these are assumed to be almost inseparable twins. These rank among the sacred phrases of our time. The belief in the coupling of science and technology is now petrified in the dictionary definition of technology as applied science, and journalistic reports under the rubric of "science news" are, in fact, often accounts of engineering rather than scientific achievements.

That belief, however, is an artifact of twentieth-century cultural attitudes superimposed without warrant on the historical record. Although the historical record shows that in the earliest civilizations under the patronage of pharaohs and kings, and in general whenever centralized states arose, knowledge of nature was exploited for useful purposes, even then it cannot be said that science and technology were systemically and closely related. By the same token, in ancient Greece (where theoretical science had its beginning), among the scholastics of the Middle Ages, in the time of Galileo and Newton, and even for Darwin and his contemporaries in the nineteenth century, science constituted a learned calling whose results were recorded in scientific publications, while technology was understood as the crafts practiced by unschooled artisans. Until the second half of the nineteenth century few artisans or engineers attended a university or, in many cases, received any formal schooling at all. Conversely, the science curriculum of the university centered largely on pure mathematics and what was often termed natural philosophy—the philosophy of nature—and was written in technical terms (and often language) foreign to artisans and engineers.

In some measure, the wish engenders the thought. Science has undoubtedly bestowed genuine benefits on humankind in this century, and it has fostered the hope that research can be channeled in the direction of social utility. But a more secure understanding of science, one less bound by the cultural biases of our time, can be gained by viewing it through the lens of history. Seen thus, with its splendid achievements but also with its blemishes and sometimes in an elitist posture inconsistent with our democratic preferences, science becomes a multidimensional reality rather than a culture-bound misconception. At the same time, a more accurate historical appreciation of technology will place proper emphasis on independent traditions of skilled artisans whose talents crafted everyday necessities and amenities throughout the millennia of human existence. Such a historical reappraisal will also show that in many instances technology directed the development of science, rather than the other way around.

In order to develop the argument that the relationship between science and technology has been a historical process and not an inherent identity, we trace the joint and separate histories of science and technology from the prehistoric era to the present. In this way we intend to review the common assumption that technology is applied science and show, instead, that in most historical situations prior to the twentieth century science and technology have progressed in either partial or full isolation from each other—both intellectually and sociologically. In the end, an understanding of the historical process will shed light on the circumstances under which science and technology have indeed merged over the past hundred years.

PART I

From Ape to Alexander

Technology in the form of stone tools originated literally hand in hand with humankind. Two million years ago a species of primate evolved which anthropologists have labeled Homo habilis, *or "handy man," in recognition of its ability, far beyond that of any other primate, to fashion tools. Over the next 2,000 millennia our ancestors continued to forage for food, using a tool kit that slowly became more elaborate and complex. Only toward the end of that long prehistoric era did they begin to observe the natural world systematically in ways that appear akin to science. Even when a few communities gave up the foraging way of life, around 12,000 years ago, in favor of farming or herding and developed radically new tools and techniques for earning a living, they established societies that show no evidence of patronizing scientists or fostering scientific research. Only when civilized—city-based—empires emerged in the ancient Near East did monarchs come to value higher learning for its applications in the management of complex societies and found institutions for those ends. The ancient Greeks then added natural philosophy, and abstract theoretical science took its place as a component of knowledge. An account of these developments forms the subject matter of part 1.*

CHAPTER 1

Humankind Emerges: Tools and Toolmakers

Scholars customarily draw a sharp distinction between *prehistory* and *history*. Prehistory is taken to be the long era from the biological beginnings of humankind over 2 million years ago to the origins of civilization about 5,000 years ago in the first urban centers of the Near East. The transition to civilization and the advent of written records traditionally mark the commencement of history proper.

Prehistory, because of the exclusively material nature of its artifacts, mainly in the form of stone, bone, or ceramic products, has inescapably become the province of the archaeologist, while the historical era, with its documentary records, is the domain of the historian. However, the single label "prehistory" obscures two distinctly different substages: the *Paleolithic,* or Old Stone Age, which held sway for around 2 million years, is marked by rudimentary stone tools designed for collecting and processing wild food sources, while the succeeding *Neolithic,* or New Stone Age, which first took hold in the Near East around 12,000 years ago, entailed substantially more complex stone implements adapted to the requirements of an economy of low-intensity food production in the form of gardening or herding.

The technologies of both the Paleolithic and Neolithic eras have left a rich legacy of material artifacts. In contrast, only a feeble record exists of any scientific interests in these preliterate societies, mainly in the form of astronomically oriented structures. Thus, at the very outset, the evidence indicates that science and technology followed separate trajectories during 2,000 millennia of prehistory. Technology—the crafts—formed an essential element of both the nomadic food-collecting economy of Paleolithic societies and the food-producing activities in Neolithic villages, while science, as an abstract interest in nature, was essentially nonexistent, or, at any rate, has left little trace.

The Arrival of Handyman

By most accounts human beings appeared on Earth only recently, as measured on the scales of cosmic, geologic, or evolutionary time. As scientists now believe, the cosmos itself originated with the "Big Bang" some 12 to 15 billion years ago. Around 4 billion years ago the earth took shape as the third in a string of companion planets to an ordinary star near the edge of an ordinary galaxy; soon the self-replicating chemistry of life began. Biological evolution then unfolded over the next millions and billions of years. In the popular imagination the age of the dinosaurs exemplifies the fantastic history of life in past ages, and the catastrophic event—probably a comet or an asteroid colliding with the earth—that ended the dinosaur age 65 million years ago illustrates the vicissitudes life suffered in its tortuous evolution. The period that followed is known as the age of mammals because these animals flourished and diversified in the niche vacated by the dinosaurian reptiles. By about 4 million years ago a line of "ape-men" arose in Africa—the australopithecines—our now-extinct ancestral stock.

Figure 1.1 depicts the several sorts of human and prehuman species that have arisen over the last 4 million years. Experts debate the precise evolutionary paths that join them, and each new fossil discovery readjusts the details of the story; yet its broad outlines are not in dispute.

The figure shows that anatomically modern humans, *Homo sapiens sapiens,* or the "wise" variety of "wise Man," evolved from a series of human and prehuman ancestors. Archaic versions of modern humans made their appearance after about 500,000 years ago, with the Neanderthals being an extinct race of humans that existed mainly in the cold of Europe between 135,000 and 35,000 years ago. Scholars differ over the modernity of Neanderthals and whether one would or would not stand out in a crowd or in a supermarket. Many scientists look upon them as so similar to ourselves as to form only an extinct variety or race of our own species, and so label them *Homo sapiens neanderthalensis*. Others think Neanderthals more "brutish" than anatomically modern humans and therefore regard them as a separate species, *Homo neanderthalensis*.

Preceding *Homo sapiens,* the highly successful species known as *Homo erectus* arose around 2 million years ago and spread throughout the Old World (the continents of Africa, Europe, and Asia). Before that, the first species of human being, *Homo habilis,* coexisted with at least two other species of upright hominids, the robust and the gracile forms of the species *Paranthropus*. At the beginning of the sequence stood the ancestral genus *Australopithecus* (or "Southern Ape") that includes *Australopithecus afarensis*—represented by the fossil "Lucy."

This sequence highlights several points of note. First is the fact of human evolution, that we arose from more primitive forebears. Among the more significant indicators of this evolution is a progression in brain

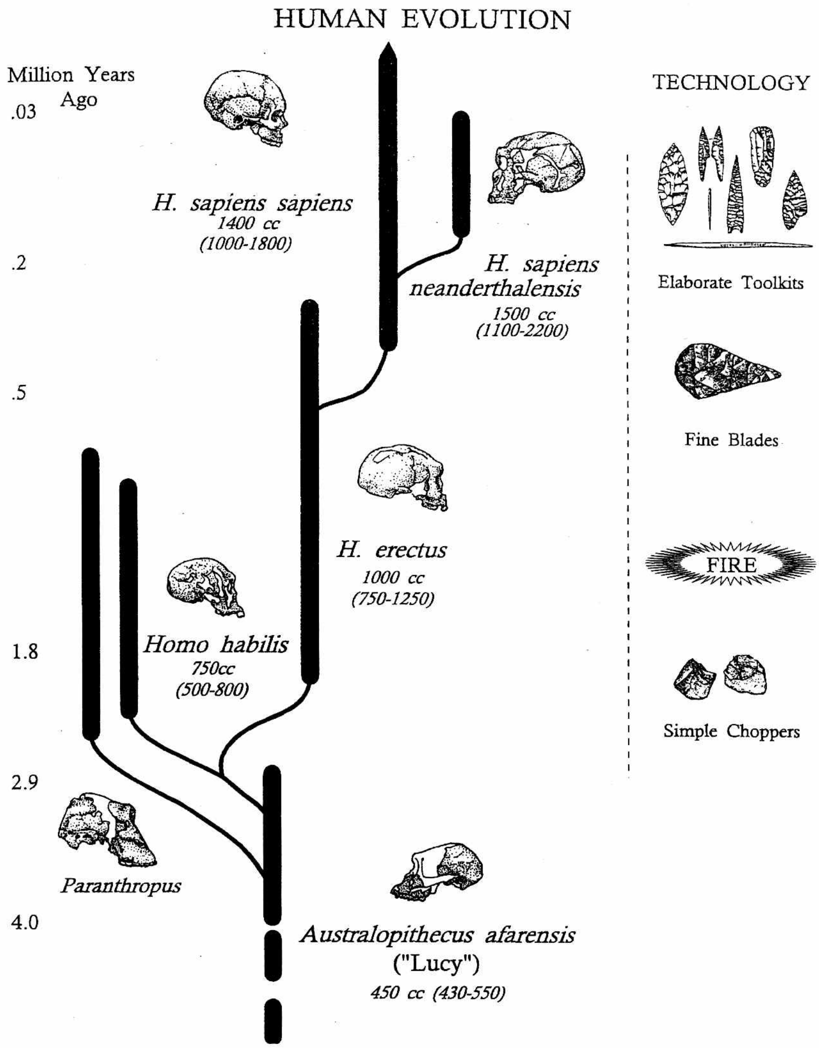

Fig. 1.1. Human evolution. Modern humans (*Homo sapiens sapiens*) evolved from earlier, now extinct, human and prehuman ancestors. (Plants and animals are classified according to the binomial nomenclature of genus and species: genus being general groups of related species, and species being specific interbreeding populations of individuals. Thus, *Homo* is the genus, and *sapiens* the species; the third name indicates a subspecies.) In general, brain size and technological sophistication increased over time, but there is no strict correlation between species and technologies. For example, *Paranthropus* and *Homo habilis* may both have used simple choppers; *H. erectus* and archaic *H. sapiens* cannot be distinguished by their respective fine-blade tool kits. Aspects of this picture are matters of debate, notably the relationship of Neanderthals to modern humans. New findings regularly shed new light on the details of human biological and cultural evolution.

size, from around 450 cubic centimeters (cc) in the case of prehuman Lucy, only slightly larger than the brain of a modern chimpanzee, through an average of 750 cc for *Homo habilis,* 1000 cc for *Homo erectus,* to around 1400 cc for humanity today. An as-yet-unexplained irony of this "progression" is that Neanderthals had slightly larger brains than today's humans.

Bipedality—or walking upright on two feet—represents another defining feature of this evolutionary sequence. Experts debate whether Lucy and her kin were fully bipedal, but her successors certainly were. An upright stance allows the hand and arm to become a multipurpose utensil for grasping and carrying items. Lucy and her type had probably adopted male-female cooperation, at least temporary pair-bonding, and a "family" structure for raising offspring.

From the point of view of the history of technology, however, the most important lesson to be drawn from figure 1.1 concerns tool use among our ancestors. It used to be thought that tool use—technology—is an exclusively human characteristic; the oldest fossil of the human genus, *Homo habilis,* received its name ("handy man") both because of its "human" skeletal features and because it was discovered along with simple stone choppers. However, the older notion can no longer be maintained. Indeed, the origin of technology is rooted in biology. Some nonhuman animals create and use tools, and technology as a cultural process transmitted from generation to generation arises occasionally among monkey and ape communities. Chimpanzees in the wild sometimes "fish" for termites by carefully preparing a twig, inserting it into a termite nest, and licking off the insects that cling to it. Since the activity is not instinctive but is instead taught to juveniles by their mothers, it must be regarded as cultural, unlike, say, the instinct of bees to build hives. Reportedly, chimpanzees have also culturally transmitted knowledge of medicinal plants, so it may be possible to identify the origins of medical technology outside of the human genus, too. Perhaps the best documented feats of technical innovation and cultural transmission in the animal world concern a single female, Imo, the "monkey genius" of a colony of Japanese macaques. Incredibly, Imo made two separate technical discoveries. First she discovered that to remove sand from potatoes thrown on the beach she could wash them in the sea rather than pick off the sand with her fingers. Then, in an even more remarkable display of ingenuity, Imo found that to separate *rice* from sand she did not have to pick out the individual grains; the mixture can be dropped into water where the sand will sink, and the rice will float and can be easily recovered. Both techniques were adopted by younger members of the troop as well as by older females and passed on to the next generation.

Claims have been made that not only *Homo habilis* but also species of *Paranthropus* probably made stone implements and may have used fire. Furthermore, little correlation exists between species type and different types of tool kits. For example, Neanderthal tools varied little from the precedents set by *Homo erectus*. The record reveals only a weak correlation between biological species and the tool kit used.

That said, however, making and using tools and the cultural transmission of technology became essential to the human mode of existence and was practiced in *all* human societies. Moreover, humans seem to be the only creatures who fashion tools to make other tools. Without tools humans are a fairly frail species, and no human society has ever survived without technology. Humankind owes its evolutionary success in large measure to mastery and transmission of tool-making and -using, and thus human evolutionary history is grounded in the history of technology.

Control of fire represented a key new technology for humankind. Fire provided warmth. Fire made human migration into colder climes possible, opening up huge and otherwise inhospitable areas of the globe for human habitation. The technology of fire also supplied artificial light, thus extending human activity after dark and into dark places, such as caves. Fire offered protection against wild animals. Fire permitted foods to be cooked, which lessened the time and effort required to eat and digest meals. Fire-hardened wooden tools became possible. And fire no doubt served as a hearth and a hub for human social and cultural relations for a million years. Their practical knowledge of fire gave early humans a greater degree of control over nature. *Homo erectus* was an exceptionally successful animal, at least as measured by its spread across the Old World from Africa to Europe, Asia, Southeast Asia, and archipelagoes beyond. That success in large measure depended on mastering fire.

The grasping hand constitutes one human "tool" that evolved through natural selection; speech is another. Speech seems to be a relatively recent acquisition, although paleontologists have not yet reached agreement on how or when it first appeared. Speech may have evolved from animal songs or calls; novel brain wiring may have been involved. But, once acquired, the ability to convey information and communicate in words and sentences must have been an empowering technology that produced dramatic social and cultural consequences for humanity.

A turning point occurred around 40,000 years ago. Previously, Neanderthals and anatomically modern humans had coexisted for tens of thousands of years in the Middle East and in Europe. Around 35,000 years ago Neanderthals became extinct, possibly exterminated through conflict with a new population, or they may have interbred and become absorbed into the modern human gene pool. A cultural discontinuity manifested itself around the same time. Whereas Neanderthals had produced simple, generalized, multipurpose tools from local materials, we—*Homo sapiens sapiens*—began to produce a great assortment of tools, many of which were specialized, from stone, bone, and antler: needles and sewn clothing, rope and nets, lamps, musical instruments, barbed weapons, bows and arrows, fish hooks, spear throwers, and more elaborate houses and shelters with fireplaces. Humans began to conduct long-distance trade of shells and flints through exchange over hundreds of miles, and they produced art, tracked the moon, and buried their dead. And yet, in terms of their basic social and economic way of life, they continued along the same path—they remained nomadic food-collectors.

Foraging for a Living

Prehistorians classify the period from 2 million years ago to the end of the last Ice Age at about 12,000 years ago as a single era. They label it the Paleolithic (from the Greek, *paleo,* "ancient"; *lithos,* "stone") or Old Stone Age. Food-collecting is its essential attribute, codified in the term *hunter-gatherer* society. Paleolithic tools aided in hunting or scavenging animals and for collecting and processing plant and animal

Fig. 1.2. "*H. erectus* Utilizing a Prairie Fire," by Jay H. Matternes. Control of fire became a fundamental technology in the human odyssey. Undoubtedly, members of the genus *Homo* first used wildfires before learning to control them.

food, and it is now understood that Paleolithic technology developed in the service of a basic food-collecting economy.

Paleolithic food-collecting bespeaks a subsistence economy and a communal society. Seasonal and migratory food-collecting produced little surplus and thus permitted little social ranking or dominance and no coercive institutions (or, indeed, any institutions) of the kind needed in stratified societies to store, tax, and redistribute surplus food. The record indicates that Paleolithic societies were essentially egalitarian, although grades of power and status may have existed within groups. People lived in small bands or groups of families, generally numbering fewer than 100. Much circumstantial evidence suggests that a division of labor based on gender governed the pattern of food collection. Although one has to allow for sexually ambiguous roles and individual exceptions, males generally attended to hunting and scavenging animals, while females most likely went about gleaning plants, seeds, and eggs as food and medicines. Men and women together contributed to the survival of the group, with women's work often providing the majority of calories. *Homo sapiens sapiens* lived longer than Neanderthals, it would seem; more true elders thus added experience and knowledge in those groups. Paleolithic bands may have converged seasonally into larger clans or macrobands for celebrations, acquiring mates, or other collective activities, and they probably ingested hallucinatory plants. Except as located in a handful of favored spots where year-round hunting or fishing might have been possible, Paleolithic food-collectors were nomadic, following the migrations of animals and the seasonal growth of plants. In some instances Paleolithic groups engaged in great seasonal moves to the sea or mountains. In the Upper Paleolithic (around 30,000 years ago) spear-throwers and the bow and arrow entered the weapons arsenal, and the dog (wolf) became domesticated, possibly as an aid in hunting.

Ice Age art is the most heralded example of the cultural flowering produced after anatomically modern humans appeared on the scene. Earlier human groups may have made beautified objects of perishable materials, but several late Upper Paleolithic cultures in Europe (30,000 to 10,000 years ago) produced enduring and justly renowned paintings and sculptures in hundreds of sites, often in hard-to-reach galleries and recesses of caves. Artists and artisans also created jewelry and portable adornments, and decorated small objects with animal motifs and other embellishments. No one has yet fully decoded what purposes cave paintings fulfilled; anthropologists have suggested hunting rituals, initiations, magical beliefs, and sexual symbolism. The many "Venus" statuettes with exaggerated feminine features, characteristic of the Paleolithic, have been interpreted in terms of fertility rituals and divination of one sort or another. By the same token, they may represent ideals of feminine beauty. But we should not overlook the technical dimension of Ice Age art, from pigments and painting techniques to ladders and scaffolding. The great cave paintings of Europe are the better known, but literally and figuratively Paleolithic peoples the world over left their artistic handprints.

Neanderthals had already begun to care for their old and invalid, and by 100,000 years ago they ceremonially buried some of their dead. Centers of mortuary and burial activity may have existed, and one can speak of a "cult of the dead" beginning in the Middle Paleolithic (100,000–50,000 years ago). Intentionally burying the dead is a distinctly human activity, and burials represent a major cultural landmark in human prehistory. They bespeak self-consciousness and effective social and group cohesion, and they suggest the beginning of symbolic thought.

It may be enlightening to speculate about the mental or spiritual world of Paleolithic peoples. What we have already seen and said of Paleolithic burials and cave art strongly suggests that Paleolithic populations, at least toward the end of the era, developed what we would call religious or spiritual attitudes. They may well have believed the natural world was filled with various gods or deities or that objects and places, such as stones or groves, were themselves alive. Religious beliefs and practices—however we might conceive them—formed a social technology, as it were, that knitted communities together and strengthened their effectiveness.