TECHNOLOGY AND SCIENCE IN ANCIENT CIVILIZATIONS

RICHARD G. OLSON

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Richard G. Olson

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Series Foreword

The lives of ancient peoples may seem far removed, socially, linguistically, and especially technologically, from the concerns of the modern world. Yet the popularity of historical subjects on both the big and little screens—*Troy, Alexander, 300*; HBO's *Rome,* the many History Channel programs—demonstrates the abiding fascination the ancient world continues to exert. Some people are drawn to the dramatic differences between the ancient and modern; others seek to find the origins for contemporary cultural features or the sources to provide meaning to our modern lives. Regardless of approach, the past holds something valuable for all of us. It is literally the root of who we are, physically through our actual ancestors, and culturally in establishing the foundations for our current beliefs and practices in religious, social, domestic and political arenas. The same ancients that we study were themselves drawn to their own pasts, often asking questions similar to the ones we pose today about our past.

The books in Praeger's series on the Ancient World address different topics from various perspectives. The ones on myth, sports, technology, warfare, and women explore these subjects cross-culturally, both within the ancient Mediterranean context—Egypt, Mesopotamia, Greece, Rome, and others—and between the ancient Mediterranean cultures and those of the Americas, Africa, and Asia. Others, including the volumes on literature, men, sexuality, and on politics and society, examine their topic more specifically within a Greek or Greek and Roman cultural framework.

All renowned scholars committed to bringing the fruits of their research to wider audiences, each author brings a distinctive new approach to their topic that differentiates them from the many books that exist on the ancient world. A major strength of the first group is their multicultural breadth, which is both informative in its comprehensive embrace and provides numerous opportunities for comparative insights. Likewise, the books in the second group explore their topics in dramatically new ways: the inner life of male identity; the contributions of both women and men to the social polity; the ancient constructions of concepts of sexuality and eroticism.

Bella Vivante
Series Editor, Praeger Series on the Ancient World

Acknowledgments

In addition to those many scholars listed in the bibliography, I owe special thanks to several persons. Chief of those is to Bella Vivante, editor of the Ancient Civilization series for Praeger, who invited me to return to topics that I had not visited for several decades just when I wanted a break from more modern materials. Second is to my Harvey Mudd College colleagues in the Department of Humanities, Social Sciences and the Arts who almost always appeared interested when I approached them with some new factoid that I wanted to regale them with and who then asked why my new bit of information was significant. Students in my Science and Technology in the Ancient and Medieval Worlds classes graciously served as test subjects for several sections of the text, catching many errors. Rudi Volti read most of the manuscript at various stages and has offered good advice, which I sometimes accepted. Individual chapters have been read by Marianne deLaet and Zoyue Wang, and Chang Tan has tried to keep my Chinese names and terms consistent with Pinyin usage. Figures 2.1 and 5.1 through 10.5 were drawn by my architect friend and golfing buddy, Nick Livingston, while all others were prepared by Joseph Emmert.

Several editors at Praeger and ABC-Clio have been friendly and helpful as they prodded and encouraged me to finish in a timely fashion and within a reasonable word limit. These include Brian Foster, Mary Theresa Church, and Elizabeth Potenza. The editorial team at Apex CoVantage is responsible for much of the clarity of the prose. As usual, my wife, Kathy Collins Olson, has been unfailingly supportive. Our new Corgi puppy, Parker, has, however, provided little but distractions.

Richard G. Olson
January 10, 2009

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One

On Definitions, Approaches, and Periodization

Imagine a tunnel through a mountain built 2,500 years ago, begun at two opposite ends, constructed solely on basic geometric principles, and which meets in the middle, only two feet off alignment. Or consider an operation done 2,000 years ago to repair a compound fracture of a femur in which a wooden rod was inserted in the bone to stabilize the recovering bone segments. When we become aware of ancient people's technical accomplishments, we marvel at their ability to achieve these results without the benefit of modern scientific advances. This book explores the development of technology and science in the major civilizations of the ancient world, exploring the extent of their achievements and trying to account for how and why different civilizations developed different forms of specific technologies and sciences.

Despite our heavily scientific and technologically oriented world, it may come as a surprise that there has been little agreement on the meaning of these terms. Hence, this chapter begins by examining what is meant by the concepts of science and technology, and just what it is we are looking for when we wish to examine the processes and products associated with them in ancient civilizations. It will continue with an overview of the approach to technology and science in the ancient world represented in this work, set against a few powerful current alternative approaches. Then, it will conclude with a brief history of the seven major cultural areas to be considered: Mesopotamia, Egypt, the Indus Valley, China, early Central America, Greece, and Rome.

DEFINITIONS OF TECHNOLOGY, SCIENCE, CIVILIZATION, AND ANCIENT

Because each of these key terms is a matter of contention among those who write about the history of technology and science, some preliminary discussion of terms will allow readers to be aware of both some of the major ideological battles among historians of ancient technology and science and where I stand on a few important contentious issues.

Technology

In many ways, the least problematic of these central terms is technology, though even this apparently simple term has come in for extensive interpretation (Oldenziel 2006). Prior to 1829, a technology was a book or study about some practical art or craft. Modern usages, which focus on the productive tools and practices themselves, were initiated by Harvard professor Jacob Bigelow in his 1829 *Elements of Technology,* and draw on the ancient Greek term *techne,* which is usually translated into the English terms art or craft, as in "the art of ship making." Well into the 20th century, however, the term was not often used, and where we would now use technology, most people used "mechanic arts," "invention," or "useful arts."

One consideration that complicates our understanding of technology has been well articulated by Wiebe Bijker in his introduction to *The Social Construction of Technological Systems.* Bijker writes:

> Technology is a slippery term. . . . Three layers of the meaning of the word can be distinguished. First, there is the level of *physical objects, or artifacts,* for example, bicycles, lamps, and Bakelite. Second, "technology," may refer to *activities or processes,* such as steel making or molding. Third, technology can refer to what people *know* as well as what they do; an example is the "know-how" that goes into designing a bicycle or operating an ultrasound device in the obstetrics clinic. (1989, 3–4)

The knowledge that is presumed to be a feature of a technology here is not the kind of formal theoretical knowledge usually associated with the notion of a science, but instead the kind of tacit knowledge that we mean when we say that someone like Joe Montana knew how to find an open receiver on the football field. In the ancient world, craft know-how was virtually always transmitted orally and/or bodily from master to apprentice and was not written down. It thus left virtually no record. Except in a few cases where we might assume that technologies in contemporary traditional societies involve a continuation of ancient practices, we have no access to this level of ancient technologies. Archeological investigations of ancient civilizations provide the most extensive knowledge of the artifactual dimension of technologies, though occasionally we do have evidence relating to processes used for producing objects, for example, when the remains of potter's wheels and kilns allow us to say something about the processes used for creating pottery.

A recent definition of technology, appearing in the Oxford University Press's *International Encyclopedia of Science and Technology,* raises another issue. It includes the following comment: "Often the term is used to describe any practical application of scientific discoveries in the production of mechanisms and in the solution of problems that confront human beings" (Luck 1999, 353). We will consider the relationships between science and technology much more extensively in the next section of this chapter, but it is certainly the case that few. if any, ancient technologies could reasonably be considered applied sciences. Indeed, ancient sciences were much more likely to emerge out of technological practices, rather than vice versa.

Finally, a definition developed by the distinguished historian of early man, V. Gordon Childe, raises another issue. He writes: "Technology should mean those activities, directed to the satisfaction of human needs, which produce alterations to the material world [along with] the results of those activities" (2004, 155). Since most arts and crafts do involve changes to the material world, it is easy to accept such a definition, but the one extensive list of *techne* which we have from the ancient world—the list of "all the arts that men possess" which Aeschylus's Prometheus presents as his gifts to humankind—includes written language, mathematics, techniques of building in brick and wood, calendrical astronomy, techniques of divination and omenology, the domestication of animals, ship building, medicine, and metallurgy (Aeschylus 1926, 449–471). Of these, at least two—calendrical astronomy and divination, or omenology—do not involve direct alterations to the material world and they meet needs or wants which are not physical but are instead social or psychological.

Rudi Volti has offered a provisional definition of technology that leaves open all of the issues mentioned above, including the relative roles of artifacts, knowledge, and organization, the degree of importance of material goals relative to social, psychological, and organizational ones, the relationship between technologies and systematic, recorded, knowledge of the natural world, and the character of the relationships between technologies and the societies from which they emerge, and I will try to be consistent in using his definition throughout what follows. Volti writes that a technology is: "a system based on the application of knowledge, manifested in physical objects and organizational forms, for the attainment of specific goals" (1995, 6). Just one comment may be important regarding this definition, especially but not solely in connection with technologies of divination. Though a technology may be aimed at a specific goal, its greatest importance may be in connection with unintended consequences. Thus, for example, in the modern world the adhesive that made Post-it Notes possible was initially developed for a completely different purpose. Similarly, in the ancient world, astronomical techniques that were initially intended to predict the outcome of terrestrial events for divinatory purposes served much more effectively for the creation of calendars. In some cases then, it seems that technologies which come into existence for one reason may, by virtue of making new opportunities available, create new demands or needs, and those cases may be of tremendous importance. The human use of fire, for example, almost certainly developed to protect humans from animals or from the cold, but once available regularly, fire provided a way to transform materials to serve a wide variety of human needs—for making bricks and pottery that would not dissolve in water, for creating edible and long lasting cooked food and drink out of inedible and/or easily rotted raw materials, and eventually for creating metal objects out of ores and valuable and useful distilled liquids out of relatively cheap and little desired raw stocks.

Science

If technology is the least problematic of our central terms, science is probably the most problematic because it has long been at the center of heated debates not only among historians from differing interpretive schools, but among self-professed scientists as well. The current controversies regarding the meaning and characterization of science grew out of a World War II and early Cold War conflict between a group of British Marxist scientists and interpreters of science, including J.D. Bernal, Benjamin Farrington, and Joseph Needham, who focused on the social and political contexts for the development and uses of science on the one hand, and a group of scientists and students of science, including Michael Polanyi, Robert Merton, and Vannevar Bush, who sought to focus on the freedom of good science from politics and social needs on the other.

The first group, which founded the Society for Social Responsibility in Science, argued that science emerged in response to the material needs of society and that it was corrupted in the ancient world when it became a kind of game to be played by a social elite freed from productive activity by the exploitation of slave labor or by the creation of a social hierarchy that divorced craft activity from theoretical concerns. The views of J.D. Bernal were and continue to be characteristic of this group and their intellectual descendants, a group that has included the vast majority of students of non-Western ancient technology and science into the present. Bernal writes:

> It was the ways of extracting and fashioning materials so they could be used as tools to satisfy the prime needs of man from which first techniques and then science arose. A technique is an individually acquired and socially secured way of doing something: *a science is a way of understanding how to do it in order to do it better.* When we come to examine in greater detail . . . the first appearance of distinct sciences and the stages of their development it will become increasingly plain that they evolve only when they are in close contact and living with the mechanism of production. (1971 Vol. 1, 47 [emphasis mine])

To give the notion that science emerges only out of practical affairs a patina of age, Marxist-influenced historians often refer to the ancient Greek historian, Herodotus, who argued that geometry emerged first in Egypt in response to the need for measuring land (geo–metry) in order to reestablish boundaries after the flooding of the Nile. Modern scholars often challenge the details of Herodotus's claim, but they continue to place the growth of mathematics in practical activities such as brick making (Chattopadhyaya 1986) or commercial record keeping (Nissen, Damerow, and Englund 1993).

If science evolves only in connection with manual activity, then it follows that one can explain why a nascent science stagnated in any particular place by pointing to social forces that tended to separate the hand from the head. Thus, Debiprasad Chattopadhyaya, the distinguished historian of ancient Indian science and follower of Bernal and Needham, argues that early Indic science associated with Harappan culture in the Indus Valley died out after approximately 1750 B.C.E. because of the rise of caste society: "The main cause of the decline of the scientific spirit in India was the entrenchment of caste society with its disastrous degradation of the social status of the technicians, craftsmen, and other manual workers" (Chattopadhyaya 1989, 9).

Opposed to the Marxist vision of a science intimately involved in productive processes was an openly anti-utilitarian and elitist strain associated with a gentleman amateur tradition that grew during the 18th and 19th centuries and which was articulated in a particularly blatant way by Henry Augustus Rowland, America's first Nobel Prize winner, in his final address as President of the American Physical Society in 1899. Speaking to his fellow physicists, he said:

> In a country where the doctrine of the equal rights of man has been distorted to mean the equality of man in other respects, we form a small and unique body of men, . . . whose views of what constitutes the greatest achievement in life are very different from those around us. In this respect we form an aristocracy, not of wealth, not of pedigree, but of intellect and ideals, holding him in the highest rank who adds most to our knowledge or who strives after it as the highest good. . . . Much of the intellect of the country is still wasted in the pursuit of the so-called practical science which ministers to our physical needs and but little thought and money is given to that grander portion of the subject which appeals to our intellect alone. (Reingold 1964, 324)

Once again, those promoting a particular view of the motives for the growth and character of science could appeal to an ancient Greek author to support their position. Aristotle's account of the early growth of mathematics, like that of Herodotus, placed its origins in ancient Egypt, but it offers a very different explanation for why it merged there. After describing the origin of the arts in his *Metaphysics,* Aristotle writes: "When all such inventions were already established, the sciences which deal neither with the necessities nor with the enjoyments of life were discovered. And this took place earliest in the places where men first began to have leisure. That is why the mathematical arts were founded in Egypt, for the priestly caste was allowed to have leisure" (981b, 20–25).

My own preference is to offer a definition of science that allows for both utilitarian and nonutilitarian motives and which incorporates the maximum number of features of modern science that can simultaneously be used regarding ancient activities with relatively few qualifications. The following definition of science, which I first articulated in 1982, will be used throughout this work:

> Science is taken to be a set of activities and habits of mind aimed at contributing to an organized, universally valid, and testable body of knowledge about phenomena. At any given time [and place] these general characteristics are usually embodied

in systems of concepts, rules of procedure, theories, and/or model investigations that are widely accepted by groups of practitioners—the scientific specialists. (Olson 1982, 7–8)

Several comments should be made about this definition. First, especially for the earliest civilizations, for which archeological evidence is often more important than textual evidence, one must infer motives and attitudes because they are not often explicitly addressed. In such cases, I will try to give at least a plausibility argument for such inferences, relating them to textual evidence that might exist in comparison civilizations. Second, the notion of testability may vary widely from one set of local circumstances to another—for many early places and times, the simple fact that a knowledge claim is useful for some purpose may be considered as a test of its legitimacy. In other places and times, meeting formal logical criteria has been a necessary and even sometimes a sufficient test of a science, while in yet other places and times, meeting certain standards of empirical confirmation has been understood to be a necessary element of testing a scientific knowledge claim. Establishing the extent of demand and the ways to provide for empirical confirmation of scientific truth claims is one of the most important ways in which the notion that a scientific community at any place and time establishes—either explicitly or implicitly—its own standards and rules of practice.

Finally, the meaning of universality may vary from local context to local context. With respect to ancient science, the term indicates that scientific knowledge was intended to be applicable to classes of phenomena rather than singular phenomena. Most ancient myths deal with unique events—the creation of the world, the origins of shade tree gardening, the success of a local army in a particular battle, the particular lightning bolt that struck Odysseus's ship, and so on. Scientific knowledge, on the other hand, was intended to explain lightning in general, the long-term repetitive behavior of the celestial bodies, the cause for the growth of all plants, and the like. In modern terms, universality is usually extended to include the claim that scientific knowledge claims should hold for all times and places. Whatever definition of universality we accept, the notion that scientists seek universally valid knowledge does not imply that they ever find it. The Christian admonition to love one's neighbor as one's self is impossible for many, if any, of us to achieve, but it nonetheless shapes the behavior of many Christians. By the same token, even though universally valid knowledge may well be impossible to achieve, the attempt to find it may well influence the behavior of those we would call scientists.

Civilization

By almost all modern secular accounts, humans have existed for at least 500,000, and probably for closer to 2 million, years. Up until just over 10,000 years ago, they all lived in tribal groups of a few dozen adults and subsisted on natural vegetation, usually gathered by women and children, and meat from wild animals, usually hunted by adult males. So, for between 98 and 99.5 percent of human existence, we were primarily hunters and gatherers using stone, bone, and wood tools and living without permanent settlements. Archeological and anthropological evidence suggests some gender-based divisions of labor, the probable existence of special shamanistic functions, and the existence of ritual acts including burials and ceremonies associated with hunting that began no later than 50,000 years ago. Then, around 10,000 years ago, both some plants and some animals were domesticated in relatively dry highland areas where grains such as wheat and barley grew naturally.

The additional food made available by dry land agriculture allowed the growth of fixed settlements, which typically housed 200–500 inhabitants, but occasionally reached populations estimated to be up to 5,000 persons with a significant division of labor at places like Catal Hüyük in southwestern Anatolia and Jericho in Palestine. Archeological evidence suggests the greater specialization of craft activities, such as painted pottery making, cloth making, leather working, the beginnings of metal working, and probably of religious functions as well, though it seems likely that even specialized functionaries also took part in primary food production for much of their time. The fortification of towns, first with stone, and then with shaped-masonry walls, began at Jericho. There is evidence of permanent private houses in open spaces to replace cave dwellings and temporary homes built of local vegetable matter, and the presence of materials that came from distant places indicates the development of extensive trade patterns. Conspicuously absent during this period of growing agriculture and pastoralism is any form of writing or any clear evidence of political hierarchy.

Approximately 5,500 years ago another transformation began to take place—what Gordon Childe labeled the first Urban Revolution (Childe 1950, 3–17), and what we identify as the rise of the first civilizations. Childe listed a series of features that characterized the formation of what he considered to be the earliest cities in Egypt, Mesopotamia, and the Indus Valley. Among the most important was the creation of more extensive settlements with higher population densities (a minimum estimated population of about 5,000 persons in a single settlement of less than one square kilometer has often been accepted as a standard). These cities incorporated classes of persons who were not engaged in primary food production but who were supported by the surplus created by irrigation agriculture and stored in communal granaries. Some of these persons were engaged in traditional crafts and in transporting and selling goods, but others were priests, managers, and military leaders who constituted a ruling class that absorbed a substantial share of the surplus in return for organizing, maintaining and protecting the public works (e.g., canals, granaries, roads, marketplaces, and houses of worship) and distributing the foodstuffs needed to sustain the city's functioning. Cities, moreover, were also characterized by the beginnings of monumental public buildings.

From our perspective, the sixth of Childe's features is particularly important:

> They [the ruling class] were in fact compelled to invent systems of recording and exact, but practically useful sciences. The mere administration of the vast revenues of a Sumerian temple or an Egyptian pharaoh by a perpetual corporation of priests or officials obliged its members to devise conventional methods of recording that should be intelligible to their colleagues and successors, that is, to invent systems of writing and numerical notation. Writing is thus a significant, as well as a convenient, mark of civilization. (Childe 1950, 14)

Because there is a sense in which we can say nothing about science in a nonliving culture that left no written records, *for our purposes writing of some kind will be taken as the defining characteristic of civilization in all that follows,* though we will not assume that Childe's account of the origins of writing are necessarily correct for all civilizations.

Childe admitted that many subsequent urbanizations, for example, those in Crete and classical Greece and Rome, did not have to exhibit all, or even many, of the features of the earliest cities because they drew on the experiences of their progenitors. He did, however, suggest that the first cities everywhere, if they were independent of the initial big three, probably emerged in much the same way. This notion was turned into a complete theory of early civilizations by the Sinologist Karl Wittfogel, whose 1957 *Oriental Despotism: A Comparative Study of Total Power* (Wittfogel 1957) extended Childe's analysis to encompass early Chinese and American Pre-Colombian societies. Wittfogel then went on to argue that the need to control and distribute water produced centralized empires and bureaucracies that were hostile to change. Given this situation, the dynamic rise of Western Europe, which avoided the early patterns of urbanization, could be understood as standing out from the background of older hydraulic civilizations.

Almost immediately after Wittfogel's 1957 publication, criticisms of his hydraulic theory of civilization began to appear. Scholars began to qualify and modify it (Adams 1960), though some elements remain in almost all subsequent discussions of the rise of civilizations. All major early civilizations did seem to arise in connection with the movement of agriculture onto the floodplains of rivers and with the consequent increases in agricultural productivity; but some early civilizations, including those of Egypt and the Pre-Columbian Americas produced written records, formal state structures, and monumental architecture long before they produced large cities. Indeed, it is not clear that the Mayan civilization ever produced cities of 5,000 or more inhabitants, nor is it clear that early China or India developed large-scale irrigation technologies like those found in Mesopotamia or Egypt. Even in Mesopotamia, life in cities and the emergence of complex social organization seems to have predated both writing and the beginnings of the large-scale irrigation systems that Childe and Wittfogel had argued necessitated both urbanization and the need for complex social arrangements. Finally, Mesopotamian culture was far from static in terms of its technology and science, and prior to the Akkadian invasions of the late third millennium, the cities of Mesopotamia tended to be independent or competitive with one another rather than constrained by any central imperial apparatus.

My goal will be to avoid accepting at the outset any particular model for how civilization must have arisen, what kinds of political organizations must emerge out of technological demands, and what kinds of political and social hierarchies are more or less likely to promote practical or theoretical innovation. These will be treated as interesting and important but open questions in what follows.

Ancient

Finally, we arrive at the decision of what to count as an "ancient" civilization. Within the Western historical tradition, which traditionally periodizes the past into ancient, medieval, early modern, modern, and contemporary eras, ancient civilization begins in Southern Mesopotamia during the mid-fourth millennium before the Common Era and ends with the fall of the Roman Empire around 476 C.E. Since archeological evidence has yet to suggest that writing appeared anywhere else prior to around 3500 B.C.E., it makes sense to pick up the story of civilization at that time and place. Furthermore, because Western readers have, by convention, looked upon the fall of Rome as the end of the ancient period in the West, we, too, shall accept that notion. But how are we to mark the end the ancient period in India, China, and Mesoamerica, where the fall of Rome had no real significance? In each specific case, I will try to choose a terminal date that makes sense in terms of local historical circumstances.

Approaches to the History of Ancient Technologies and Sciences

The attempt to understand the origins and decline of science in connection with status hierarchies in society has occasionally led Marxist-oriented historians into an alliance with another tradition that has had great importance in connection with the history of science—a tradition associated with the term positivism and the doctrines of the early 19th century French philosopher and historian of science Auguste Comte. For present purposes, the most important feature of Comte's positivism is his Law of Three Stages. According to this law:

> Each of our leading conceptions—each branch of our knowledge—passes successively through three different historical conditions: the Theological, or fictitious; the Metaphysical, or abstract; and the Scientific, or positive. In other words, the human mind, by its nature, employs in its progress three methods of philosophizing, the character of which is essentially different, and even radically opposed: viz., the theological method, the metaphysical, and the positive. (Comte 1855, 25)

From this positivist perspective, science and religion must ultimately always be in conflict with one another, and religion can function in relation to science only by establishing barriers to the growth of science—which represents a later and more advanced stage of thought. Marxism, as a materialist and atheistic perspective, shares with positivism its antagonism to religion and Marxist scholars have often appropriated the antireligious arguments of positivist historians, especially when they see priesthoods as initiating the kind of status hierarchies that value intellectual activity over material production. I have argued extensively elsewhere on both theoretical and empirical grounds against the Positivist and Marxist claim that science and religion are inevitably at war with one another (Olson 2004, 5–7). Here it is enough to point out that, in most cases for which we have compelling evidence regarding ancient civilizations, religious and secular medical traditions coexisted in relative peace, and in the case of ancient Greece, the greatest flowering of Aesclepiad (religious) healing and post-dated the highest period of rational Hippocratic medicine, rather than preceded it. There were undoubtedly places and times when it is appropriate to see specific sciences and specific religions in some sort of competition or conflict with one another in the ancient world, but as we shall see, there were also times and places in which religious traditions motivated and propagated scientific knowledge and learning and in which scientific knowledge played a central role in promoting a new religion. In what follows, I will always consider science and religion interactions as matters open to a wide range of interpretations rather than restricted a priori to hostile ones.

Just as Marxist scientists and historians of science found support for some of their key arguments in the anti-theological elements of positivism, those who sought the autonomy of science from social pressures found support in other aspects of positivism. Comte argued that science was pursued for two all but unrelated motives—the satisfaction of a psychological need to dispose facts in a comprehensible order regardless of any notion of utility and the prediction of phenomena in order to be able to act in and on the world. That is, he argued that both nonutilitarian and utilitarian aims operate in motivating scientific activity. But Comte insisted that even if one was developing scientific knowledge for purposes of application, it was only if one could step back and produce a value-free, dispassionate knowledge, that knowledge would provide a completely adequate foundation for subsequent action. What had led the astrologers, alchemists, and medical practitioners of antiquity astray was their passionate interest in the outcome of their investigations. Only by establishing what we now call an objective stance, freed from emotional attachment, can true scientific knowledge be generated. Thus, he wrote in an essay of 1822, "Admiration and reprobation of phenomena ought to be banished from every positive science, because all preoccupations of this sort directly and unavoidably tend to hinder or mislead examination. Astronomers, physicists, chemists, and physiologists [unlike astrologers, alchemists, and physicians] neither admire nor blame their respective phenomena. They observe them" (Lenzer 1975, 54).

Comte and his 19th century followers had generally agreed that, while positive knowledge was the most reliable available at any time and place, it could not achieve the status of absolute and universal truth. Thus, Comte wrote:

> The study of the laws of phenomena must be relative since it supposes a continuous progress of speculation subject to gradual improvement of observation, without the precise reality ever being fully disclosed: so that the relative character of scientific conceptions is inseparable from the true idea of natural laws, just as the chimerical inclination for absolute knowledge accompanies every use of theological fictions and metaphysical entities. (Comte 1855, 453)

This recognition is particularly important as we consider scientific knowledge in ancient civilizations, for the fact that from our present perspective ancient authors were either vague or completely wrong does *not* mean that they were not being scientific.

It is important to understand that the question of whether a Marxist-oriented historiography of science or an intellectualist historiography is more nearly correct is not a well formulated or answerable question, because the two traditions *define* science in different ways, one insisting upon the close connection between science and technology and one explicitly insisting upon a separation. Each definition has met the needs of a particular community for a significant period of time, and both traditions have provided important insights into the creation of ancient understandings of the character of the uniformities to be discovered in the behavior of entities in the world. Recently, however, scholars have begun to develop approaches to the history of science and technology which open up, rather than foreclose, questions regarding such issues as the relationships between science and technology at particular places and times and the relationship between religious traditions and scientific ones. There is, of course, not complete agreement among these various scholars regarding how to define science.

Nationalism and the Historiography of Science and Technology

The study of ancient science and technology in some locations has not only been subject to biases induced by ideological commitments to Marxism, positivism, democracy, or intellectual freedom, it has also been subject to nationalistic and/or anti-Eurocentric biases. Ancient documents and artifacts have thus often been interpreted (and possibly distorted) in such a way as to make them appear more consistent with modern cosmopolitan scientific ideas and practices or technological artifacts than might seem reasonable to a less biased interpreter because the authors have wanted to glorify a tradition with which they identify. Gyan Prakash has, for example, discussed the tendency for early Indian nationalists to interpret Vedic (early Hindu) texts in ways that seem implausible to many scholars today in order to find the origins of much scientific knowledge in ancient India (Prakash 1999).

My Own Eclectic Approach

With respect to issues of bias, I take a position often called feminist point of view epistemology. That is, I doubt seriously whether any scholar can be completely objective and unbiased no matter how hard he or she tries. I thus welcome those scholars who openly admit their points of view, for that invites the reader to be particularly careful in evaluating their arguments and evidentiary claims. In this spirit, I should admit that, while I hope that I am not Eurocentric in the sense that I would deny the non-Western origins of many important technologies and scientific developments, I am inclined to be skeptical of claims of great antiquity unsupported by archeological or strong textual evidence because I know that claims of antiquity have been used to give authority to knowledge claims in many cultures. Similarly, I am inclined to favor the idea that comparable artifacts or arguments have independent origins in different cultures unless a strong case can be made for cultural borrowing because I am convinced both that responses to similar problems in similar environments are likely to be similar and because of the important role that contingency plays in history. Again, I find the analogy with evolution suggestive. We know that eyes developed independently in many evolutionary contexts, in each of which chance variations played a large role. For the same reason, we might expect that similar technologies might have developed independently in different places.

Though not a theist, I am a practicing member of an organized religion, so I am inclined to grant religion both positive roles and negative ones in society. I am by temperament what Steven Jay Gould called a lumper, rather than a splitter. That is, I am more inclined to be fascinated by the likenesses among apparently diverse things than to emphasize the differences among apparently like things, so I will probably focus on the similarities between technologies and sciences in different ancient contexts when I can find them, though I will not completely ignore differences. Finally, I seem to have a special affinity for the ironic, so I am inclined to notice and remark on the unexpected and counterintuitive connections among things.

The Structure of This Book and My Choice of Technologies and Sciences to Emphasize

I am particularly interested in technologies and sciences in ancient civilizations for three fundamental reasons, each of which plays a role in the structure of this book. First, mainstream history of science has been written almost exclusively from a Western perspective. Until very recently, even histories of non-Western scientific traditions, including the monumental studies of Chinese science done by Joseph Needham and his collaborators (Needham, et. al. 1954–2004) have primarily reflected Western scientific practices and values. Serious attempts to compare the conditions of scientific knowledge production and use in different civilizations began primarily with a series of explorations of Attic Greek and Chinese science and medicine by G. E. R. Lloyd and by Lloyd and Nathan Sivin, which were initiated fewer than 15 years ago (Lloyd 1996; Lloyd and Sivin 2002); and the first English-language textbook to attempt to integrate the history of science and technology into a world- historical and not exclusively Eurocentric account appeared only in 1999 (McClellan and Dorn 1999).

My goal is to extend the comparative approach initiated by Lloyd and Sivin—though not just their great emphasis on political ideology—beyond China and Greece to most of the major civilizations of the ancient world. This goal has led to the thematic structure of the book in which each chapter explores an isolated technology and science cluster across multiple civilizations rather than a broad range of sciences and technologies in each isolated civilization. I have neither the expertise nor the space to offer the detail achieved by Lloyd and Sivin, but I do hope to offer an approach that is both deeper than that of McClellan and Dorn and more insistently comparative.

Second, my primary interests involve those technologies and sciences that were most centrally implicated in the daily experiences of the citizens of ancient civilizations—those that involved the production and distribution of food, shelter, and clothing as well as their landscapes and mindscapes. These interests are well served by emphasizing the *techne* listed by Prometheus, which include mathematics (chapter 2), written language (chapter 3), astronomy (chapters 4 and 5), divination (chapters 4 and 6), medicine (chapters 6 and 7), construction methods (chapter 8), and metallurgy/mineralogy (chapter 10). To these topics I have added one, the production, distribution, and consumption of food (chapter 9) that Prometheus hints at in *Prometheus Bound* by mentioning the domestication of animals. (Aeschylus 1926, 463–465). In part because the earliest archeological investigations of early civilizations were carried out in connection with military occupations and by European military officers engaging in their hobbies, ancient military technologies have received much attention elsewhere, thus I have felt no need to pay special attention to them, though I have not avoided military considerations where they have been important in connection with construction and metallurgy, for example.

Finally, because I am by training and inclination fascinated by theoretical knowledge as much as or more than by knowledge that is immediately embodied in the daily practices of material production, I have chosen to emphasize the variety of ways in which technological traditions and what I identify as theoretical, or scientific, traditions interacted in ancient civilizations. These emphases are special focal points in chapters 2, 3, 4, 7, and 10.

Historical Background

Before turning to the technologies and sciences of ancient civilizations, we pause here to briefly provide the basic geographical and political settings for what follows. Even if we do not fully subscribe to Wittfogel's hydraulic theory of civilization, there is no doubt that local geography helps to account for important features of each ancient civilization that we will be discussing.

Mesopotamia

Sumerian civilization developed initially in the late fifth millennium near the mouths of the Tigris and Euphrates Rivers, where they produced a marshy alluvial fan as they emptied into the Persian Gulf, which then reached much farther north than it does now. Living in small villages in reed huts, the earliest Sumerians subsisted by farming, fishing, and herding. As time went on, the climate became dryer, and it seems to have become necessary to begin to irrigate fields during the dry season. Since the spring floods of the Tigris and Euphrates Valley were generally short lived and violent, dikes to protect agricultural lands, to divert water into holding ponds, and to provide for irrigation in the dry had to be massive and sturdy—small-scale systems would not do—thus emerged the large cities and social hierarchies suggested by Childe and Wittfogel. At least during the initial period of rapid growth, however, the major cities of ancient Sumer seem to have been largely independent of one another and dominated internally by large temple complexes whose leaders served as the central managers of the agricultural economies and food distribution networks in the name of the gods that they served. The chief priests were literally the "chief tenant farmers of the god X."

Because the Mesopotamian floodplain produced large agricultural surpluses but was relatively destitute of both wood and minerals, temple complexes also entered into trade with peoples as far away as the Indus Valley and the British Isles to get both raw materials and finished goods. In the earliest days, several temple complexes might exist within a single city, though as time went on it became more common for a single temple complex to dominate. By the mid-third millennium, these cities, which were very rich by the standards of the time, became tempting targets for invaders from the hills and for neighboring cities. Organizational leadership tended to pass from the priests to military kings and their retainers, who slowly wrested control of economic resources from the temples. By the late third millennium, Akkadian invaders had assumed military and political control and had formed the formerly independent cities into an empire usually controlled by the king of Babylon, which provided the political, economic, military, and intellectual leadership of the region from around 2000 B.C.E. until the invasion of the armies of Alexander the Great around 330 B.C.E.

Egypt

Around 5000 B.C.E., settlements were established in the Nile River Valley, nearly 900 years earlier than those documented for Mesopotamia. As North Africa became increasingly arid between around 9000 B.C.E. and 5000 B.C.E., people began to settle in the valley of the Nile, the longest river in the world, which carried water down from the mountains in East Africa to the Mediterranean Sea. Because there were major deposits of metals in what is now the desert surrounding the canyon created by the river, these people seem to have brought copper and gold with them. By around 4000 B.C.E., villages dotted the canyon floor over a nearly 660-mile path. The valley varied from less than a mile and a half in width at Aswan to about 11 miles near el-Amarna and then spread out into a marshy delta as the Nile split into many channels north of Memphis and made its way to the sea. During the period between about 3800 B.C.E. and 3200 B.C.E., the villages and towns of southern, or upper Egypt, were first united into small dominions ruled over by chiefs and then into a single kingdom. Northern, or lower Egypt, which constituted the delta region, seems to have been somewhat more loosely organized, but around 3100 B.C.E., northern and southern Egypt were unified under a single king, who became identified as a divine pharaoh.

Though the annual floods of the Nile could vary tremendously in depth and extent, causing serious problems both when they were too high and long and when they were too low and short, the floodwaters typically rose and retreated slowly, arriving sometime in mid-June and departing in mid October, leaving a rich layer of wet silt over the land and the underground aquifers filled. Irrigation ditches were dug to carry water past the normal edges of the river during the dry season, but the only maintenance they usually needed was minor clearing because currents rarely exceeded 10 miles per hour at the center of the river even during the highest floods. There was, therefore, little reason for the agricultural population to congregate in large cities to construct and maintain complex irrigation systems during the Archaic period (c. 3200–2780 B.C.E.), which included the first two dynasties.

During the Early Dynastic period, as the central government became increasingly powerful, large administrative centers became full-fledged cities. This, or Thinis, probably reached around 10,000 inhabitants during the early Old Kingdom period (c. 2780–2130 B.C.E.), which included dynasties 3–6, and Memphis became even larger when the center of government moved there around 2200 B.C.E. The early Old Kingdom period saw Egypt divided into 42 administrative regions, or nomes, each presided over by a provincial governor, or nomarch, whose primary allegiance was to the central government. Initially, these nomarchs tended to move from one nome to another throughout their careers, so they did not develop strong local power bases. During the second half of the third millennium, however, the central government became weaker, probably as consequence of a long dry period with weak floods that decimated the economy. Consequently, local officials grew in strength, leading to a period during which strong families became the hereditary nomarchs of nomes. There was a second flowering of central authority during the Middle Kingdom (c. 1938–1630 B.C.E. and dynasties 11–14) followed by a period of foreign rule over all but a small region around Thebes by a people known as the Hyksos. Thebian leaders recaptured the Nile Valley and Delta, spreading outward into an empire that included part of the eastern Mediterranean during the New Kingdom, which flourished