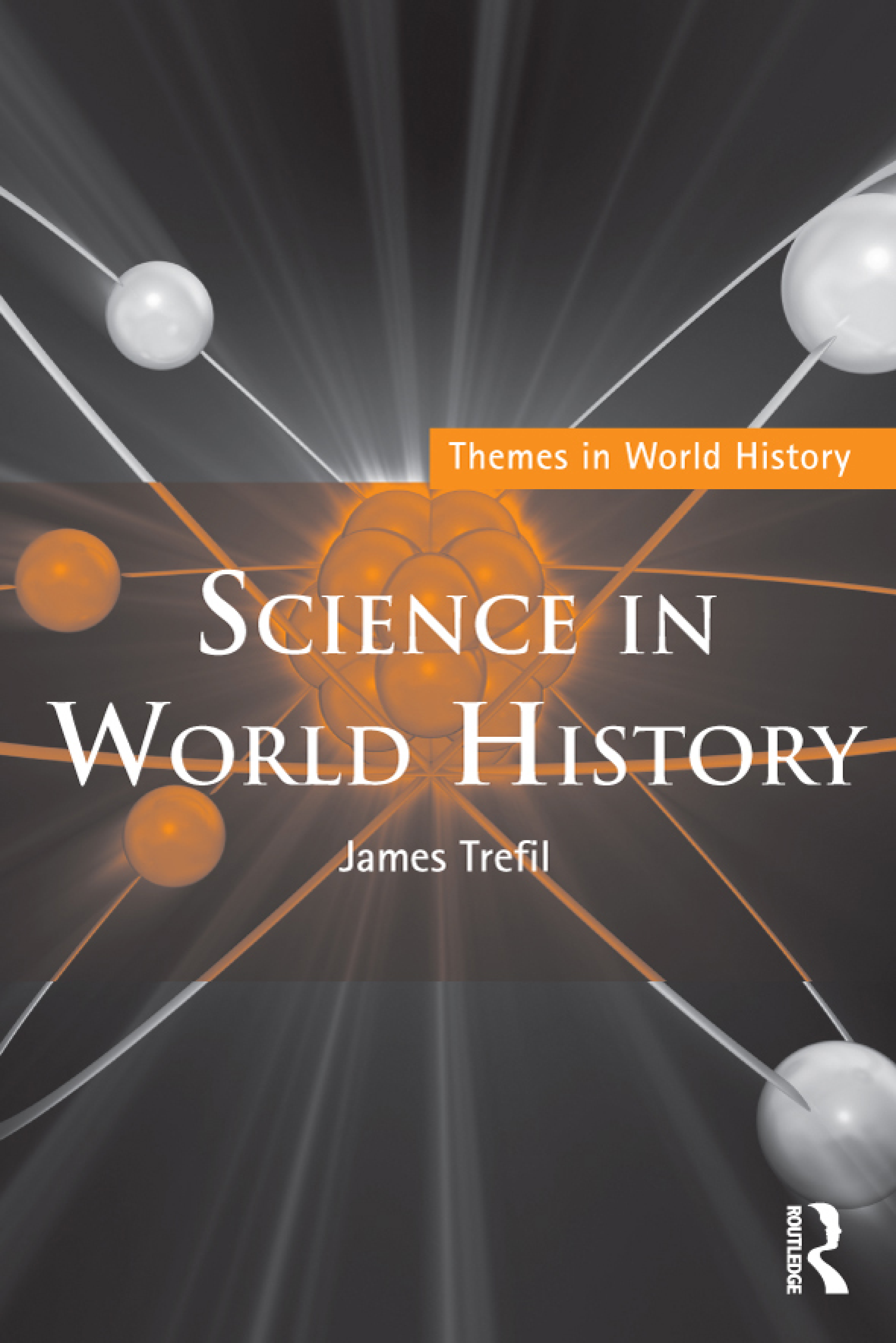

Themes in World History

SCIENCE IN WORLD HISTORY

James Trefil

ROUTLEDGE

Science in World History

Science today is a truly global enterprise. This book is a comprehensive, thematic survey of the history of science from its roots in different cultures around the world through to the present day.

James Trefil traces how modern science spread from its roots in Western Europe to the worldwide activity it is today, exploring crucial milestones such as the Copernican revolution, the germ theory of disease, and the theory of relativity. In doing so, he also examines the enormous social and intellectual changes they initiated. Opening with a discussion of the key elements of modern scientific enterprise, the book goes on to explore the earliest scientific activities, moving through to Greece and Alexandria, science in the Muslim world, and then on to Isaac Newton, atomic theory and the major developments of the nineteenth century. After examining the most recent scientific activities across the world, the book concludes by identifying future directions for the field.

Suitable for introductory courses and students new to the subject, this concise and lively study reconsiders the history of science from the perspective of world and comparative history.

James Trefil is Clarence J Robinson Professor of Physics at George Mason University. Author of over 40 books and the recipient of numerous awards, he is renowned for his ability to explain science to non-scientists.

Themes in World History

Series editor: Peter N. Stearns

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James Trefil

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To my grandaughter Sophia

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Chapter 1

What is science?

Imagine for a moment that you were an extraterrestrial approaching the planet Earth for the first time. What would you notice?

There are lots of candidates for answers to this question. You might, for example, exclaim over the presence of liquid water on the planet's surface—a rare phenomenon in the universe. You might wonder why the atmosphere was full of a corrosive, poisonous gas that the natives called oxygen. But my guess is that you would notice something else. Among the life forms present, you would notice that one species—the one that calls itself *Homo sapiens*—is somehow different. Alone among the millions of living things on the planet, this species has spread over the entire habitable surface, converted vast tracts of forest and grassland to farms, and built an interconnecting grid of massive cities. It has dammed rivers, built highways, and even come to dominate some of the natural chemical cycles that operate in the planet's ecosystems. While closely related to all the other life forms at the molecular level, this species is just … well … different.

Why?

I would suggest that the answer to this question lies in one simple fact. Human beings are the only life form on Earth that has developed a method that allows them to understand the universe around them (what we call science) and the ability to use that understanding to transform the environment to their advantage (what we call technology). It is these twin abilities, developed over millennia, that have allowed humanity to prosper as it has.

In fact, I will go so far as to argue that the really deep changes in the human condition—the ones that produce fundamental differences in our world—arise because of advances in science and technology. Let me give you two examples to back up this claim.

Forty thousand years ago our ancestors eked out a fragile existence as hunter-gatherers, harvesting the food that nature provided for them. Then, over a long period of trial and error culminating around 8000 BCE, some of them (probably mostly women) discovered that life didn't have to be lived that way. They observed the way that wild plants grew and realized that instead of being satisfied with what nature offered in the way of nourishment, they could plant seeds, tend the growing crops, and harvest the final product. The enterprise we call agriculture was born and the world has never been the same. The surplus of food allowed human beings to begin building cities, where arts and learning could grow. To be fair, it also allowed for the existence of standing armies, another, perhaps less welcome, aspect of modern life. But in any case, those early farmers, without writing, mostly without metal tools, used their observations of the world to change it forever.

Fast forward ten thousand years, to England in the latter half of the eighteenth century. This was a country poised to become the greatest empire the world had ever seen, a country with enormous social and class inequalities, and one whose major colony in North America was on the brink of declaring independence. Suppose you imagine yourself in London in 1776 and ask a simple question: what is going on in this country that will have the greatest impact on human life over the next couple of centuries?

I would suggest that if you wanted to answer this question you wouldn't go to the great universities or to the seats of government. Instead, you would go to a small factory near Birmingham, to the firm of Watt and Boulton, where the Scottish engineer James Watt was perfecting his design of the modern steam engine.

A word of background: there were steam engines in existence before Watt, but they were cumbersome, inefficient things. A two-story high engine, for example, developed less power than a modern chain saw. What Watt did was to take this cumbersome device and change it into a compact, useable machine.

Seen in retrospect, this was a monumental advance. For all of human history the main source of energy had been muscles—either animal or human—with small contributions from windmills and water wheels. Suddenly, the solar energy that came to Earth hundreds of millions of years ago became available, because it was trapped in the coal that was burned in Watt's steam engine. This engine powered the factories that drove the Industrial Revolution, the railroads that tied together continents, the cities where a greater and greater proportion of humanity spent their lives. The machines being built in that grubby factory were the agents of a fundamental change in the human condition. And whether you think this is a good thing (as I do) or a deplorable one (as has become fashionable in some circles), you can't deny that it happened.

Science and technology

In this book we will look at a number of other discoveries and developments that have had (or are having) the same sort of deep effect. The development of the electrical generator transformed the twentieth century, breaking forever the ancient link between the place where energy is generated and the place where it is used. The germ theory of disease changed the way medicine was done, producing unheard of lifespans in the developed world. The development of the science of quantum mechanics led to the digital computer and the information revolution that is transforming your life even as you read these words.

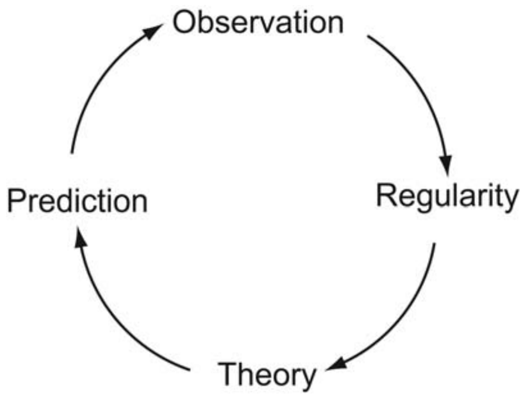
While it is indisputable that science and technology have changed our lives, we need to understand the differences between the two of them. In everyday speech they have come to be used almost interchangeably, but there are important distinctions that need to be made. As implied in the previous discussion, science is the quest for knowledge about the world we live in, technology the application of that knowledge to satisfying human needs. The boundaries between these two activities are fuzzy at best, with large areas of overlap—indeed, we will spend a good portion of Chapter 11 exploring in detail the process by which abstract knowledge is turned into useful devices. For the moment, however, we should just keep in mind the notion that these two terms refer to different sorts of processes.

Science and technology, then, go a long way toward explaining what the hypothetical extraterrestrial with which we started the discussion would observe. And this, of course, leads us to a number of interesting questions: what exactly is science, and how did it arise? How similar to modern science was the work of previous civilizations, and in what ways did their approaches differ from our own and from each other? Are there any activities that are common to every scientific endeavor? Before we get into a detailed description of the way that science is practiced in the twenty-first century, let's look at these historical questions.

The historical question

Later in this chapter we will describe the modern full blown scientific method in some detail, but for the moment we can picture it as a never ending cycle in which we observe the world, extract regularities from those observations, create a theory that explains those regularities, use the theory to make predictions, and then observe the world to see if those predictions are borne out. In simple diagrammatic form, we can picture the normal modern scientific method as a clockwise cycle (see overleaf).

One way of asking the historical question, then, is to ask what parts of this cycle various civilizations of the past used. The first two steps—observation of the world and the recognition of regularities—are pretty universal, and probably predate the appearance of *Homo sapiens* on the evolutionary scene. No hunting-gathering group would last very long if its members didn't know when fish would be running in a particular stream or nuts would be ripening in a particular forest. Indeed, we will argue in the next chapter that many pre-literate civilizations developed a rather sophisticated astronomy based on regular observations of the sky. The existence of structures like Stonehenge in England



and the Medicine Wheels of western North America testify to this sort of development. An important lesson we learn from these sorts of structures is that it is possible to pass complex information about the natural world from generation to generation through the oral tradition, even in the absence of writing.

The absence of written records makes it difficult to know what, if any, theories these early peoples developed to explain what they saw. This situation changes when we look at the civilizations of Mesopotamia and Egypt. Here we run into a strange dichotomy. The Babylonians kept the best astronomical records in the ancient world—in fact, their data was still being used by Greek astronomers centuries after it was recorded. As far as we can tell, however, they seemed totally uninterested in producing a theory to explain their findings. It seems that if they were able to look at the data and figure out when the next eclipse would occur, they were satisfied. In terms of the cycle pictured above, they seemed to get off the train with regularities and not be interested in going any further.

The Egyptians are more typical. They told stories about what they saw in the sky, explaining the motion of the heavenly bodies in terms of the adventures of the gods. Whether this sort of explanation of nature constitutes a "theory" is a tricky question, depending as it does on how you define the word "theory." The point, however, is that once you explain any natural phenomenon in terms of the whims of the gods, you lose the power to make real predictions, since in principle those whims can change at any time. In this case, you are limited, as were the Babylonians, to relying on past regularities to forecast the future. As far as we can tell, this was the case for most of the advanced ancient societies we'll be studying.

The people who broke out of this mold were the Greek natural philosophers, who first began to construct theories based on purely naturalistic explanations of the world. By the first century CE, in fact, natural philosophers in Alexandria had put together a marvelously complex model of the solar system capable of making rudimentary predictions about things like eclipses, the rising and setting of the planets, and the time of the new moon.

During what are called the Middle Ages in Europe, the center of gravity for the development of science moved to the Islamic world (see Chapter 5) and progress was made in many areas—we will look specifically at mathematics, medicine, and astronomy. If you had to pick a date for the development of the modern scientific process, however, you would probably talk about the work of Isaac Newton in England in the seventeenth century (see Chapter 6). This is when the full blown scientific method outlined above made its appearance—the time when we went "all the way around the cycle."

Modern scientists tend to reserve the word "science" for the development that started with Newton (or, sometimes, with Galileo some decades earlier). In essence, they tend to regard what came before as a kind of "pre-science." Since this is common usage among my colleagues, I will use it, but in what follows I would urge you to keep in mind that one of the greatest failings of those who study history is to judge the past by the standards of the present. To my mind, the illiterate men and woman responsible for Stonehenge were every bit as good a set of "scientists" as my colleagues in any university science department of which I've been a member. The proper question to ask is not "How close did this ancient civilization come to what we do today?" but "What did they do and how did it fit in to their cultural life?"

Having said this, however, the modern scientific method can serve as a useful template that will help us organize the accomplishments of the various ancient civilizations we will study. It is useful, therefore, to examine this method in its current form, a subject to which we will devote the rest of this chapter.

The modern scientific method

Before we launch into this subject, I want to make a strong caveat—one that I will emphasize at the end of the chapter as well. Science is a human endeavor, carried out by human beings no different from the rest of us. One well known characteristic of human behavior is an aversion to blindly following rules. Like artists and musicians, scientists often delight in departing from the path of tradition and striking out on their own. Thus, what follows should be thought of as a list of elements found in most scientific work, more or less in the order in which they can normally be expected to appear. It should not be thought of as a kind of "cookbook" that all scientists follow at all times.

Observation

All science begins with observation of the world. It is important to point out that the idea that you can learn about the world by observing it, an obvious proposition to those of us living in secular, technology driven societies, has not been a universal given throughout most of human history. There are, in fact, many ways of approaching the problem of learning about the universe. In Chapter 4, for example, we will talk about the approach taken by many Greek philosophers, an approach in which the power of human reason, rather than observation, was the main tool for exploration.

We can see another way of approaching the world in the seemingly endless debate about the inclusion of creationism (or its latest incarnation, intelligent design) in the science curriculum in American public schools. On one side of this debate is the scientific community, relying on data gathered from the fossil record and modern measurements of DNA—data gathered, in other words, through observations of the world. On the other side we have people for whom a literal interpretation of the creation story in the Book of Genesis is taken as the inviolable, unquestionable, eternal word of God. For these people, the truth about the universe is contained in revered texts, and observations have nothing to do with it. For at least some creationists, it is impossible to imagine any experiment or observation that would convince them to change their minds. For people who think this way, in other words, you do *not* learn about the world by observation, but by consulting the sacred texts.

So with the caveat in mind that not all human societies would agree with the statement, we will begin our discussion of the scientific method with the following:

> If you want to learn about the world, you go out and observe it

We will take this to be the first step in the development of modern science and, as we have argued, it was a step taken by many societies in the past. Having said this, however, we have to point out that there are many different kinds of "observation," each appropriate for a different area of science.

When most people think about what scientists do, they think about experiments. An experiment is a specific way of observing nature, usually under highly controlled (and somewhat artificial) circumstances. The basic strategy is to change one thing in a physical system and see how that system changes as a result.

A classic example of this approach to observation can be seen in the Cedar Creek Natural History Area near Minneapolis. There, scientists from the University of Minnesota have been studying the way that plant ecosystems respond to changes in their environment. They set up their experiment by having many plots of ground a few yards square. Every plot gets the same amount of rain and sunshine, of course, but the scientists can change the amount of other materials on the plots. For example, they can add different amounts of nitrogen to some plots and none to others, then watch the way the different plots evolve over the summer. This is a classic example of a controlled experiment. (For the record, the experiment I've just described showed that adding nitrogen increases the biomass in a plot, but lowers its biodiversity.)

In many sciences, this sort of finely controlled experiment can be done, but in others it cannot. An astronomer, for example, cannot build a series of stars to see the effect of adding a particular chemical element to the system, nor can a geologist go back and watch rock layers forming on the early Earth. Scientists in these sorts of fields have to depend more heavily on pure observation rather than experimentation. This doesn't affect the validity of the science, of course, but it's important to keep in mind that knowledge is acquired in a slightly different way.

Finally, as we shall point out in Chapter 12, the advent of the digital computer has introduced yet another meaning to the term "observation." Over the past couple of decades, as computers have gotten more powerful and our knowledge of the details of physical systems has grown, scientists have started to assemble massive computer programs to describe the behavior of complex systems—everything from the future of the climate to the evolution of ecosystems to the formation of planets. It is becoming more and more common for scientists to "observe" something like the formation of a planetary system by changing parameters in a computer program, in much the same way as the Minnesota scientists varied the amount of nitrogen in their plots. This sort of "observation" is usually referred to as "modeling" or "simulation."

Having made these distinctions, it is important to remember that whether scientists start their work with experiments, observations, or simulations, they always begin with a reference to what is seen in the external world.

Regularities

After you observe the world for a while, you come to an important realization: events do not happen at random. In fact, the world we inhabit is surprisingly regular and predictable. The sun always rises in the east and sets in the west, for example, and the days get longer and shorter with the seasons in a predictable way. So predictable is the world, in fact, that even ancient civilizations without writing were able to construct massive monuments like Stonehenge to mark the passage of time—a topic to which we'll return in the next chapter. Noticing and stating these regularities is the second important step in the scientific process. We have noted that most civilizations have reached this step in the scientific process. In fact, most of the activities we now characterize as "crafts" actually represent the accumulated experience of generations of people observing the natural world.

It is at the stage of finding regularities that those of us who teach science often begin to encounter a problem, because these regularities are often stated in a strange language—the language of mathematics—rather than in English. Mathematics is a somewhat artificial language that has the enormous advantage of having a high level of precision. Unfortunately, it is also a language