ON THE SHOULDERS OF GIANTS

THE HISTORY OF SCIENCE

FROM THE ANCIENT GREEKS TO THE SCIENTIFIC REVOLUTION

Ray Spangenburg and Diane K. Moser

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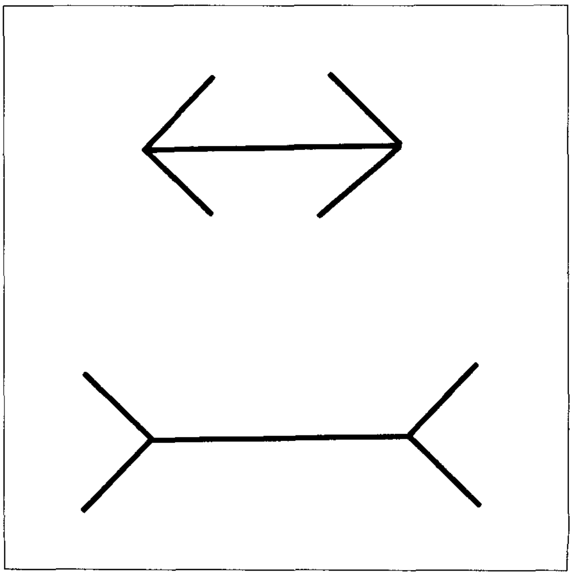
PREFACE TO THE SERIES

. . . our eyes once opened, . . . we can never go back to the old outlook. . . . But in each revolution of scientific thought new words are set to the old music, and that which has gone before is not destroyed but refocused.

—A. S. Eddington

What is science? How is it different from other ways of thinking? And what are scientists like? How do they think and what do they mean when they talk about "doing science"?

Science isn't just test tubes or strange apparatus. And it's not just frog dissections or names of plant species. Science is a way of thinking, a vital, ever-growing way of looking at the world. It is a way of discovering how the



Looks can be deceiving: These two lines are the same length.

world works—a very particular way that uses a set of rules devised by scientists to help them also discover their own mistakes.

Everyone knows how easy it is to make a mistake about what one sees or hears or perceives in any way. If you don't believe it, look at the two horizontal lines on page vi. One looks like a two-way arrow; the other has the arrow heads inverted. Which one do you think is longer (not including the "arrow heads")? Now measure them both. Right, they are exactly the same length. Because it's so easy to go wrong in making observations and drawing conclusions, people developed a system, a "scientific method," for asking "How can I be sure?" If you actually took the time to measure the two lines in our example, instead of just taking our word that both lines are the same length, then you were thinking like a scientist. You were testing your own observation. You were testing the information that we had given you that both lines "are exactly the same length." And, you were employing one of the strongest tools of science to do your test: you were quantifying, or measuring, the lines.

More than 2,000 years ago Aristotle, a Greek philosopher, told the world that when two objects of different weights were dropped from a height the heaviest would hit the ground first. It was a common-sense argument. After all, anyone who wanted to try a test could make an "observation" and see that if you dropped a leaf and a stone together the stone would land first. Try it yourself with a sheet of notebook paper and a paperweight in your living room. Not many Greeks tried such a test though. Why bother when the answer was already known? And, being philosophers who believed in the power of the human mind to simply "reason" such things out without having to resort to "tests," they considered such an activity to be intellectually and socially unacceptable.

Centuries later, Galileo Galilei, a brilliant Italian who liked to figure things out for himself, did run some tests. Galileo, though, like today's scientists, wasn't content merely to observe the objects fall. Using two balls of different weights, a time-keeping device, and an inclined plane, or ramp, he allowed the balls to roll down the ramp and carefully *measured* their movement. And, he did this not once, but many times, inclining planes at many different angles. His results, which still offend the common sense of many people today, demonstrated that, if you discount air resistance, all objects released at the same time from the same height would hit the ground at the same time. In a perfect vacuum (which couldn't be created in Galileo's time), all objects would fall at the same rate! You can run a rough test of this yourself (although it is by no means a really accurate experiment), by crumpling the notebook paper into a ball and then dropping it at the same time as the paperweight.

Galileo's experiments (which he carefully recorded step by step) and his conclusions based on these experiments demonstrate another important attribute of science. Anyone who wanted to could duplicate the experiments, and either verify his results or, by looking for flaws or errors in the experiments, prove him partially or wholly incorrect. No one ever proved Galileo wrong. And years later when it was possible to create a vacuum (even though his experiments had been accurate enough to win everybody over long before that), his conclusions passed the test.

Galileo had not only shown that Aristotle had been wrong. He demonstrated how, by observation, experiment and quantification, Aristotle, if he had so wished, might have proven himself wrong—and thus changed his own opinion! Above all else the scientific way of thinking is a way to keep yourself from fooling yourself—or from letting nature (or others) fool you.

Of course, science is more than observation, experimentation and presentation of results. No one today can read a newspaper or a magazine without becoming quickly aware of the fact that science is always bubbling with "theories." "Astronomer at X Observatory Has Found Startling New Evidence that Throws into Question Einstein's Theory of Relativity," says a magazine. "School System in the State of Y Condemns Books that Unquestioningly Accept Darwin's Theory of Evolution," says a newspaper. "Bizarre New Results in Quantum Theory Say that You May Not Exist!" shouts another paper. What is this thing called "theory"?

Few scientists pretend anymore that they have the completely "detached" and objective "scientific method" proposed by the philosopher Francis Bacon and others at the dawn of the scientific revolution in the 17th century. This "method," in its simplest form, proposed that in attempting to answer the questions put forward by nature, the investigator into nature's secrets must objectively and without preformed opinions observe, experiment and gather data about the phenomena. "I make no hypotheses," Isaac Newton announced after demonstrating the universal law of gravity when it was suggested that he might have an idea *what gravity was.* Historians have noted that Newton apparently did have a couple of ideas, or "hypotheses," as to the possible nature of gravity, but for the most part he kept these private. As far as Newton was concerned there had already been enough hypothesizing and too little attention paid to the careful gathering of testable facts and figures.

Today, though, we know that scientists don't always follow along the simple and neat pathways laid out by the trail guide called the "scientific method." Sometimes, either before or after experiments, a scientist will get an idea or a hunch (that is, a somewhat less than well thought out hypothesis) that suggests a new approach or a different way of looking at a problem. Then he or she will run experiments and gather data to attempt to prove or disprove this hypothesis. Sometimes the word *hypothesis* is used more loosely in everyday conversation, but for a hypothesis to be valid scientifically it must have built within it some way that it can be proven wrong if, in fact, it is wrong. That is, it must be falsifiable.

Not all scientists actually run experiments themselves. Most theoreticians, for instance, map out their arguments mathematically. But hypotheses, to be taken seriously by the scientific community, must always carry with them the seeds of falsifiability by experiment and observation.

To become a theory a hypothesis has to pass several tests. It has to hold up under experiments, not just by one scientist conducting the experiments or making the observations, but to others performing other experiments and observations as well. Then when thoroughly reinforced by continual testing and appraising, the hypothesis may become known to the scientific or popular world as a "theory."

It is important to remember that even a theory is also subject to falsification or correction. A good theory, for instance, will make "predictions"—events that its testers can look for as a further test of its validity. By the time most well-known theories such as Einstein's theory of relativity or Darwin's theory of evolution reach the textbook stage, they have survived the gamut of verification to the extent that they have become productive working tools for other scientists. But in science, no theory can be accepted as completely "proven"; it must remain always open to further tests and scrutiny as new facts or observations emerge. It is this insistently self-correcting nature of science that makes it both the most demanding and the most productive of humankind's attempts to understand the workings of nature. This kind of critical thinking is the key element of doing science.

The cartoon-version scientist portrayed as a bespectacled, rigid man in a white coat, certain of his own infallibility, couldn't be farther from reality. Scientists, both men and women, are as human as the rest of us—and they come in all races, sizes and appearances, with and without eyeglasses. As a group, because their methodology focuses so specifically on fallibility and critical thinking, they are probably even more aware than the rest of us of how easy it is to be wrong. But they like being right whenever possible, and they like working toward finding the right answers to questions. That's usually why they became scientists.

This book and the four others in this series, On the Shoulders of Giants, look at how people have developed this system for finding out how the world works, making use of both success and failure. We will look at the theories scientists put forth, sometimes right and sometimes wrong. And we will look at how we have learned to test, accept and build upon those theories—or to correct, expand or simplify them.

We'll also see how scientists have learned from others' mistakes, sometimes having to discard theories that once seemed logical but later proved to be incorrect, misleading, too limited or unfruitful. In all these ways they have built upon the shoulders of the men and women of science, the giants, who went before them.

C O N T E N T S

PART ONE

PRECURSORS OF SCIENCE: FROM ANCIENT TIMES TO THE MIDDLE AGES

CHAPTER 1

LEGACIES FROM ANCIENT PEOPLES

It was as if someone suddenly opened a window and let the fresh air pour into a long-closed and musty room. Nearly 2,500 years ago, as the fresh Mediterranean air breezed along the sun-drenched buildings of the seaports of ancient Greece, people began to look at the world differently than they ever had before. What was this new outlook of the ancient Greeks—this remarkable break from the views of the past?

Today when we refer to the most famous of the early Greek thinkers we call them *philosophers*, based on the original meaning of the word, those who love and search for knowledge or wisdom. The tremendous contribution made by these thinkers was the belief that ordinary human beings could hope to understand the workings of nature. As basic as this belief seems to us today, it was a momentous and heroic act of self-confidence on the part of the early Greeks. It was the first glimmer of science—not as we know it today, but its precursor. Those preceding them had never even dreamed that the human mind could venture into this territory, once believed to be governed by the capricious whims of spirits and gods.

What emboldened the Greek philosophers to take such an audacious step? Why, at that particular point in human history, did they make this tremendous shift in perspective that opened up the doors of knowledge? Who were their precursors, how did they set the stage and how were the Greeks different?

BEFORE THE GREEKS: MEASUREMENT AND MYTHOLOGY

Far back in time, long before any civilization for which we have records, the first humans began asking basic questions about the world around them.

Questions such as: What are those points of light in the night sky? What is night and why is it different from day? Why does a tree fall? What is fire and why does it burn? Why does smoke rise and wood become ash? What is a human and what is an animal and how are they different? How do some plants sustain life when eaten, while others are poisonous? What is life? What is death? Is a stone alive?

And they began to devise answers based on what they thought they saw. The earliest, most primitive answers explained most natural events—the seasons, the wind, the growing of plants, the flooding of rivers—in terms of spirits. Spirits, though not seen, were thought to dwell everywhere in nature—in rocks, in the wind, in the clouds, in the river. Like people, they could be happy, angry, sad or jealous. A river flooded because the river spirit or god was angry and wanted to punish. Spirits also could be flattered or persuaded or cajoled: Rain came to water the fields because the rain gods were pleased or had been appeased.

Throughout the long dawn of humankind's history most views of the world were of this spiritual or mythological kind. People developed systems for trying to influence the world around them—to cure illness, end droughts, win wars or prevent floods—by using magic to call on the spirits or gods. They used incantations and potions. They tried to read signs by examining dead animals' livers. They made sacrifices. And sometimes, due to coincidences, these methods seemed to work. Whenever they worked, the spiritual view of the world was reinforced. When they didn't work, people tended to think they'd done the potion or incantation wrong rather than disbelieve that spirits were at work.

But, at the same time, ancient peoples began developing other tools to control the world around them—tools that worked more reliably. During the Old Stone Age (possibly as long ago as 2.4 million years), they began to fashion materials and make weapons for hunting. By Neolithic times, or the New Stone Age (about 6,000 to 10,000 years ago), they understood enough about how plants grew to be able to plant and grow their own food, and agriculture was born. These advances were purely practical—technological, not scientific—but they were some of the earliest examples of people using logic and putting ideas together to understand some small part of the world.

Large-scale agriculture began when, about the fourth millennium B.C., the Sumerians in the Tigris-Euphrates River valley first hooked animals up to a plow and to wheeled carts. These people also built ships, which meant they soon needed to devise methods of navigation across the seas. By 5,000 years ago the Sumerians were combining copper and tin to make bronze, and metallurgy was born. The Egyptians on the Nile, meanwhile, were making many of the same advancements.

By this time urban civilizations existed in the areas around the perimeter of the Mediterranean, and trade and agriculture had become complex enough that records had to be kept. Both the Sumerians and the Egyptians developed numeric systems and methods of keeping accounts, a job that was entrusted to priest-administrators. The Sumerians developed a cuneiform method of writing on clay tablets, and the Egyptians used hieroglyphs on papyrus. They developed mathematical tables: multiplication, division, squared numbers and square roots.

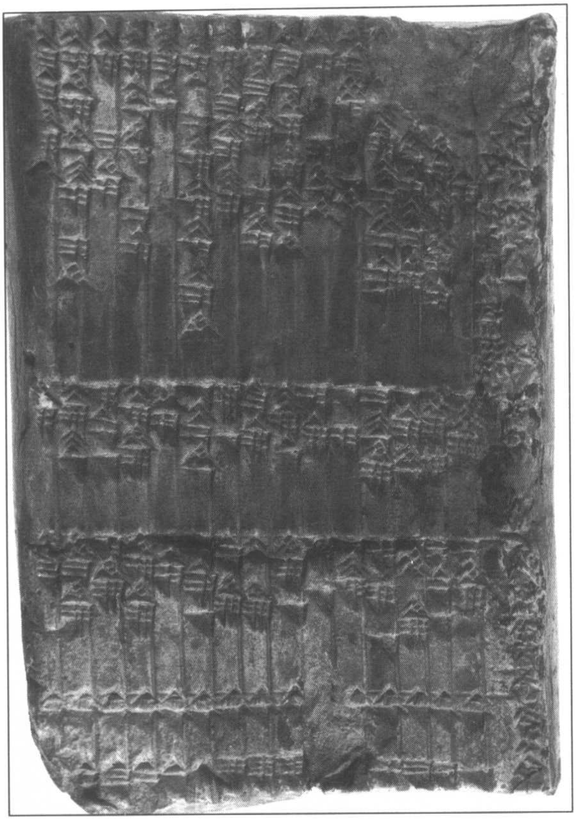
By about 4,000 years ago another tribe, the Babylonians, ascended to power in Mesopotamia. Much of the calendar system we use today was conceived by the Babylonians, based on their close observations of the Sun, Moon and planets. Their motivations were both practical and spiritual. On the practical side, they needed a way to keep track of time—to anticipate the changes in seasons and the flooding of rivers. Their spiritual interest came from their belief in a system known as astrology that supposed that the positions of the planets controlled people's lives. The Babylonians' observations of the night sky, given the tools they had to use, were amazingly accurate and served as stepping stones for astronomers to come.

All of this, too, strictly speaking, was technology, not science—the development of tools and methods for bettering human life, not knowledge for the sake of knowledge. But, in developing these technologies, people were developing the tools that later generations, even thousands of years later, would use to search for answers about how the world worked.

Today we take so many of these tools completely for granted that it's easy to overlook the extraordinary progress these early peoples made. Any 10-year-old can recite a multiplication table. But how many of us could come up with a numerical system that worked? (One proof of the difficulty is the fact that both the Romans and the Egyptians came up with systems that made multiplying and dividing very awkward. Try multiplying VII by XXXII.) The first person to create bronze or smelt iron had to have come upon the process as the result of experimentation, observation and thinking. In Central America, early peoples discovered that they could remove the poison from the cassava plant and use its tuberous roots, once freed of the poison, for food. To make this discovery, these people, too, must have gone through a process of investigation and use of logic—some of the same processes that science would come to rely on.

But the birth of science was still a long way off. Up to the end of the Bronze Age (about 5,500 to 3,000 years ago) no people had gone beyond developing practical intellectual tools, systems and technologies for managing the civilizations they had built. Some, like the Babylonians, had made excellent observations and calculations in the service of astrology. But all of them still made magic an important part of their world view and none of them asked why or looked for natural causes.

Then a combination of circumstances and events made it possible for an entirely different point of view to develop. By about 3,300 years ago



Replica of a Babylonian tablet (Smithsonian Institution, photo #64196)

alphabets were born in Phoenicia (one based on the Babylonian cuneiform system, the other on Egyptian hieroglyphics) and writing as well as reading were simplified, enabling people other than trained priests to communicate by the written word. Also, sometime after about 4,000 years ago, in the Armenian mountains, a group of people developed an efficient method to smelt iron out of iron ore. As the method of smelting iron became more prevalent, by about 1,000 years later, some of these tribes to the north gained military strength (among them a group known as the Dorian Greeks) and began conquering the civilizations of the high Bronze Age.

THE ANCIENT GREEKS: NEW WAYS OF LOOKING AT THINGS

The collection of tribes known as the Dorian Greeks flowed down in waves from the northwest and north central mainland into the Macedonian peninsula (the area now known as Greece) and the eastern Mediterranean.

Because of the isolation of the communities they formed, hundreds of independent city-states came into existence over the following centuries. These city-states were loosely associated but were left free to form their own governments and subcultures. No central authority dictated philosophy, and, while priests and priestesses were consulted for predictions and wisdom, they did not have the far-reaching economic and political power that their counterparts held elsewhere.

The Macedonian peninsula, with its many inlets and nearby islands, lent itself readily to the development of a seafaring economy, and the Greeks traveled, traded and colonized widely. They developed a keen spatial sense of the world around them—the kind of geometric mind-set that comes with navigation and travel. And they soon discovered that world views differed vastly from one corner of the Mediterranean to another. Some of what they saw seemed useful to them, and some didn't—but uncommitted as they were, they were free to choose the ideas and systems that seemed to work best and discard what did not.

Like other ancient civilizations, the Greeks had developed an elaborate mythology, peopled with gods, goddesses, nymphs, fates, muses and other inhabitants of a spirit world. But, unlike some other cultures, they saw their gods as fallible (though larger than life) and neither all-powerful nor all-knowing. As a result, Greek thinkers were perhaps less inclined to use supernatural explanations and more apt, because of their experience with the seas and other civilizations, to look for natural causes.

So, given the Greeks' lack of a central authority governing the city-states, their exposure to other cultures, and the relative openness of their own mythological system, they were ripe for a new way of looking at the world. But it was also curiosity that led the Greeks to make the transition from reliance on myth to a search for knowledge. They sought to find general patterns in nature, to find order. "Why" seemed like a good question to the Greeks because it helped to open their eyes, to look for these patterns and generalizations that would help them see order behind all the apparent variations.

Not everything about the way the Greeks looked at the world was productive. As we'll see, thinkers for many generations after the Greeks often followed too closely in their footsteps. Most of the Greek philosophers relied too heavily on subjective thought and intellectual exercises and too little on observation or experiment. Their concepts originated primarily within their minds: They developed ideas about how nature should work and then they tried to fit nature to their ideas.

But they gave us the first gateway into a world of natural causes, a world that could be explored and explained, that people could understand—a world revealed through simple analogies, not religious dogma or superstition. The Egyptians, Babylonians and others who had gone before had