

Introduction

Philosophy and Operationalism

I Knowledge and its history

What is knowledge? A bird, we say, knows how to fly. But we would not like to claim that it therefore knows aeronautics: there have never been avian Wright brothers.

There is much invested in the word "knowledge," and as with any word that bears many connotations, this one has a long and complex history. An understanding of the meanings that it carries for us today will therefore require a journey into the regions of the past where those meanings were first created in a recognizably modern form. One of the most important is the Europe of the sixteenth and seventeenth centuries, a time and place that, in the history of science, is usually known as the Scientific Revolution.

The global practice that we call science is still, in the twenty-first century, coordinated with primary reference to centres of training and research that look to the European tradition. This tradition was first adopted elsewhere on a large scale in the United States, often with the help of European training and European émigrés, and only in the twentieth century did it become naturalized elsewhere. Nobel prizes in the sciences even now go predominantly to scientists in Europe and North America, including scientists from elsewhere in the world who received their training and conducted their research in those places. An historical understanding of that characteristically modern enterprise must therefore look first to its development in a European setting.

The idea that something particularly important to the emergence of European science occurred in the sixteenth and seventeenth centuries is one that Europeans themselves first claimed in the eighteenth century. The period from the work of Copernicus in the early sixteenth century, which put the earth in motion around the sun, up to the establishment of the Newtonian world-system at the start of the eighteenth – which included universal gravitation as part of an indefinitely large universe – came to be regarded

Dear, Peter. Revolutionizing the Sciences: European Knowledge and Its Ambitions, 1500-1700. Princeton: Princeton University Press, 2001.

as a marvellous "revolution" in knowledge unparalleled in history.¹ Naturally, this perspective included an appropriate evaluation of what had gone before. The European learning of the Middle Ages, on this view, had been backward and empty. Philosophers had been slaves to the ancient writings of Aristotle; they had been more concerned with words and arguments than with things and applications. It is a view that still lives on in popular myth, despite the radical historical re-evaluations of the Middle Ages, accomplished during the past century, that have given the lie to such a dismissive caricature of medieval intellectual life. Nonetheless, some aspects of the eighteenth century's celebratory account of its recent forebears deserve continued attention. For all that it was exaggerated and self-congratulatory, the idea that there was a fundamental difference between medieval learning and the new learning brought about by the recent "revolution" contains an important insight. Medieval learning, on this account, had stressed the ability to speak about matters of truth; whereas now, instead, there was a stress on knowledge of what was in the world and what it could do.

This book will, in effect, examine how much justice that view contains. The story will be more complicated than the easy triumphalist accounts of the eighteenth century, however. We are nowadays less confident than the spokesmen of the Enlightenment that there had been an unambiguous triumph of rationality over obfuscation, or that our own modern science is a neutral and inevitable product of progress. That science is a part of the culture that nurtures it has been shown time and again by so-called "contextualist" historical and sociological studies of specific cases; science, they have shown, is made by history. The central goal of the history of science is to understand why particular people in the past believed the things they did about the world and pursued inquiries in the ways they did. The historian has no stake in adjudicating the truth of past convictions. No historical understanding of Copernicus's belief in the motion of the earth around the sun comes from the proposition that his belief *was true*. Copernicus believed what he did for various *reasons*, which it is the job of the historian to find out; truth or falsity are determined by arguments, and it is the arguments that can be studied historically.

In explaining historical change, many factors may be invoked, often different ones in different cases. A difficulty in historical work arises from its complexity and the frequent singularity of the events or situations being addressed. It is as if a geologist were to be called upon to explain why a particular mountain happened to be exactly as high as it was, no more and no less. The elevation of such mountains might be explicable in terms of general geological processes, but the exact details of the appearance of any particular one would be too much dependent on the unknown, accidental contingencies of its history. Historians, similarly, cannot provide deductive causal accounts of why a particular event, such as the English Civil War, took place in the way that it did. They can attempt, however, to make

generalizations about what conditions rendered such an event more or less likely. Another way of seeing this is to move away from talking about the likelihood of outcomes, to speak instead of *understanding*. The historian wants to understand aspects of the past in the same sort of way as we understand what was involved in our neighbour's winning the lottery, even though we could not have predicted it.

In the Scientific Revolution, similar issues were at stake for investigators of nature. Their medieval predecessors, destined to be pilloried in the eighteenth century, had aimed above all at *understanding* the natural world; the new philosophers typically aimed, by contrast, at successful prediction and control. It was not a matter of doing the same thing better – it was a matter of doing something *different*. The literate culture of the High Middle Ages (roughly, the twelfth century to the fourteenth century) had grown up around the medieval universities, in which it was generally known as "scholasticism." These new institutions were to a greater or lesser degree associated with the church and with its cultural agenda. As a result, at universities such as those of Paris or Oxford theology was the first among their higher faculties (those granting the doctorate); it was routinely known as "the queen of the sciences." Scholarly prestige tended as a result to accrue to abstract philosophizing intended to serve the establishment of truth; this was the rational counterpart of belief, and spoke to intellectual conviction rather than practical know-how.

The central discipline concerned with knowledge of nature was called "natural philosophy" (*philosophia naturalis* or, often, *scientia naturalis*). Other disciplines also dealt with nature, such as medicine (another of the higher faculties) and the mathematical sciences. These latter, apart from arithmetic and geometry, encompassed studies of those aspects of nature which concerned quantitative properties – areas such as astronomy, music theory, or geometrical optics. Natural philosophy, however, was pre-eminent among all these because it took its central goal to be the philosophical explanation of all aspects of the natural world. It was generally conducted using the relevant writings of Aristotle; because Aristotle had used the Greek word *physis* to refer to the whole of the natural world, living and non-living, the medieval Latin word *physica*, or "physics," was routinely used as a synonym for "natural philosophy."

II How a medieval philosopher thought about the natural world

All revolutions are revolutions against something. One way of doing things is overturned, to be replaced by another, different one. If there really was a scientific "revolution," it must by necessity have overthrown a previous orthodoxy – which is precisely the way the story was told three centuries ago. It is, in fact, unclear to what extent an old, unchallenged orthodoxy had actually existed, or to what extent the ways of thought that replaced it were themselves truly novel and truly unified. But every tale needs a begin-

ning, and the taken-for-granted beliefs of the majority of natural philosophers in the medieval universities provide us with ours. We must therefore examine the commonplaces of the scholastic-Aristotelian view of natural knowledge, so that we know a little of what everyone with a university education knew too.

Aristotelian philosophy was aimed at *explanation*. Aristotle was not interested in "facts" themselves so much as in what he called the "reasoned fact." That is, he wanted to know things by knowing *why* things were the way they were. Mere description of the obvious properties of an object or process (such as its measurable features) would not, in itself, serve that explanatory goal; it would merely provide something to be explained. But this does not mean that the senses, the source of the description, were devalued. On the contrary, Aristotle had emphasized that all knowledge ultimately comes by way of the senses. Without the senses, nothing could be known, not even the truths of mathematics; the latter, like all other items of knowledge, derived by abstraction from sensory awareness of particulars. The apparently abstract character of medieval Aristotelian philosophy, the feature most pilloried in the eighteenth century, justified its procedures by reference to just such a sensory basis. It was not, however, any kind of experimental ideal that would be recognizable to modern eyes.

To an Aristotelian, sensory knowledge about the world served as the starting place for the creation of properly *philosophical* knowledge. Consider the following argument, a standard example in medieval logic:

All men are mortal
Socrates is a man
Therefore Socrates is mortal.

Pieces of sensory information resembled the final line (technically, the "conclusion" of this "syllogism"): "Socrates is mortal." This is a specific assertion about Socrates that can be made only on the basis of sensory experience of that particular person and his actual death. The first line, however (the "major premise"), that "all men are mortal," is a universal assertion about *all* men everywhere and at all times. It cannot itself be justified as certain by reference to a delimited set of individual sensory observations. And yet certainty was one of Aristotle's requirements for proper "scientific" demonstration. During the seventeenth century, critics such as the Englishman Francis Bacon criticized Aristotelian logical procedures based on the syllogism for being circular. The universal assertion constituting the major premise could, Bacon said, only be justified on the basis of countless singulars, of which the conclusion in any given instance would itself be an example. So the conclusion was being demonstrated on the basis of a philosophical, universal knowledge-claim that was itself in part *justified* by the conclusion.²

Bacon's criticism should alert us to something unfamiliar in Aristotelian

philosophical procedures. Bacon's point was a straightforward one well within the capacities of the enormously logically-sophisticated scholastic philosophers. And yet they did not tend to see it as a meaningful objection. The crucial issue of the move from particular experiences of the world to universally valid (and hence philosophical) generalizations was usually seen as unproblematic. "Experience" for a scholastic Aristotelian did not mean the sensory perception of single events, as might be involved in recording an experimental outcome. Instead, according to Aristotle, "from perception there comes memory, and from memory (when it occurs often in connection with the same thing), experience; for memories that are many in number form a single experience."³ In effect, Bacon's difficulty is collapsed into a psychological habit; a habit, moreover, that is simply assumed to constitute a legitimate cognitive process. The usual ways in which human beings go about making their knowledge (whether explanatory or inferential) is thus not to be questioned; Aristotle provides a natural history of knowledge rather than a critical epistemology. The Aristotelian position amounts to saying: "If that is what we do, then that is what knowledge is."

Aristotelian experience, in practice, amounted to knowledge that had been gained by someone who had perceived "the same thing" countless times, so as to become thoroughly familiar with it. The rising of the sun every day (making due allowance for cloud-cover) would be an example of such experiential knowledge. That heavy bodies fall downwards was also known to everyone from daily experience, which is why Aristotle could appropriately use it in providing a philosophical explanation of the nature of heavy bodies in his *Physics*.⁴ When an Aristotelian philosopher claimed to base his knowledge on sensory experience, he meant that he was *familiar* with the behaviours and properties of the things he discussed. Ideally, his audience would be too. Therein lay the biggest difficulty.

Besides its putative experiential foundations, Aristotelian natural philosophy also claimed to be a *science* (the Latin word used by the scholastics for Aristotle's Greek *epistēmē* was *scientia*). A true science demonstrated its conclusions from premises that were accepted as certain. Demonstrative conclusions would be certain as long as they were deduced correctly from starting points that were themselves certain; mere likelihood was insufficient. This was a very tall order. Aristotle appears to have modelled his conception of an ideal science on the Greek mathematical practice of his day: the kind of geometry exemplified in Euclid's *Elements* (c.300 BC) uses as its starting points statements that are taken to be immediately acceptable, being either conventional (definitions) or supposedly self-evident (postulates and axioms). From this foundation, Euclid attempts to derive often unforeseen conclusions regarding geometrical figures by rigorous deduction. Aristotle, in his work *Posterior Analytics*, mandated a similar scheme for all formal bodies of knowledge that aspired to being sciences, regardless of their specific subject-matter. Not surprisingly, Aristotle's ideal

found no concrete exemplification outside of Greek mathematics itself. It is difficult to imagine an Aristotelian deductive science of zoology (a field of especial interest to him).

Nonetheless, the lure of demonstrative certainty drew scholastic natural philosophers to believe that they could make knowledge that was analytically solid: terms would be defined in such a way as to permit logically unassailable deductions. Thus, one might define the element "earth" as that substance which has as its natural place the centre of the universe (Aristotle's universe was geocentric). Then, one could easily explain, at least in principle, the centrality of the earthy sphere on which we live (it is where all heavy, meaning earthy, bodies have accumulated), as well as the tendency of heavy bodies to fall downwards (seeking their natural place). It was this kind of explanatory strategy that would look to later critics as a matter of purely verbal trickery.

The Aristotelian reliance on experience that was already universalized (in that sense, already "common knowledge") yielded a natural philosophy that was centrally concerned with explanation *rather than* other goals. The intent was to understand phenomena that were *already known* – there is no pressing sense in which scholastic natural philosophers thought of their enterprise as one of making *new discoveries*. The change in goals represented by the development of such a view is one of the most characteristic features of the large-scale mutations in thought found in the seventeenth century. Discovery itself came most often to be described in geographical terms; in the 1660s, Robert Hooke of the newly-founded Royal Society of London spoke of the microscope as opening up new territories for discovery in the realm of the very small. The expansion of the European perspective brought about by the voyages of discovery to the New World, and the attendant increase in worldwide commerce, made such a metaphor immediately available and accessible. Near the beginning of the seventeenth century, Francis Bacon had made much use of the same image of discovery, and even chose a prophecy from the Book of Daniel to express his programmatic ambitions: "Many shall pass through, and knowledge will be increased."⁵ In effect, the world had begun to contain many more things than had been dreamt of in scholastic philosophy.

It is important to recognize, however, that the newly emerging types of natural philosophy that challenged Aristotelianism by the seventeenth century were not simply more efficacious. If they put an increased premium on discovering new things, it was not so clear (to many scholastic-Aristotelians, at least) that they made better sense of phenomena that were already known. One of the serious intellectual and cultural battles of the period concerned challenges to the Aristotelian ideal of intelligibility, and attempts at replacing it. Such battles offered to supplant Aristotle's kinds of physical explanation by mechanical explanations of natural processes that involved tiny particles or atoms, or by mathematical formalisms that

were sometimes associated with the name of Aristotle's teacher, Plato. Adherence to the older models of natural philosophical explanation and the categories that they used long remained a viable intellectual option; it simply became increasingly unfashionable.

Explanatory schemes changed, but so too did research practices. Replacing the Aristotelian stress on known phenomena with one focused on novelty also often involved changing the conception of experience as it was used in the making of natural knowledge. Where Aristotle's "experience" spoke of what was known about how the world routinely behaves, the seventeenth century saw increasing recourse to deliberately fabricated experiments that revealed behaviours that had sometimes never been seen before. Experimental investigation relied on the notion that what nature can be made to do, rather than what it usually does by itself, will be especially revealing of its ways. Francis Bacon spoke of experimentation as being a matter of "vexing" nature; perhaps significantly, as a government agent in the closing years of Queen Elizabeth's reign Bacon had valued torture (an extreme form of vexation, to be sure) as a way of forcing information from taciturn suspects.⁶ For Aristotelians, by contrast, the philosopher learned to understand nature by observing and contemplating its "ordinary course," not by interfering with that course and thereby corrupting it. Nature was not something to be controlled.

Thereby hangs a major, and signal, difference between the older academic philosophy of nature and the enterprise that emerged from the "Scientific Revolution." It is as well to have an accurate understanding of what is at stake in the use of that term before attempting to explain it, and the theme of operationalism is as effective a summing-up of the wide body of changes as any. It captures the core issues behind the abandonment of much of Aristotelian views of nature: this was not a critique of means, as Bacon himself observed, so much as of ends.

So do birds *know* how to fly? Does a cook *know* what bread is? Bacon would have answered "no" to the first question, and "maybe" to the second. A cook should not be said to "know" about bread in a philosophical sense simply by virtue of being able to make it, any more than a bird "knows" about flight by virtue of being able to fly. But Bacon believed that a philosophical cook, who already possessed true knowledge about bread, would by definition be able to make it well, because a criterion for knowing truly the nature of something is the ability to reproduce it artificially. The proof of the pudding was in the cooking. Hence Bacon's scorn for Aristotelian natural philosophy: it offered explanations that did not speak to operation; that could not be put to work.

The subject of this book, in short, is a wholesale and profound restructuring of ideas about nature, of the proper purposes of knowledge about nature, and of ways of acquiring that knowledge. The large-scale cultural developments that brought about these new intellectual and social values, and thereby created new senses of what it might mean to understand some-

thing, are more than just entertaining window-dressing for a story about the emergence of modern science. They are integral parts of what modern science itself is – what it is about and what its procedures mean.

III Renaissance and revolution

The story can be divided into two stages. Although the term "Scientific Revolution" has long been used for the entire period considered by this book, it will refer here specifically to the seventeenth century. The first of our two stages can, by contrast, be called the "Scientific Renaissance."⁷ The period of European history known as the Renaissance is one that, depending on region, lasted from the end of the fourteenth century until the start of the seventeenth. Its relevance to our concerns arises from its broad cultural rôle in most areas of intellectual endeavour, including the scientific, with its widest impact being felt only in the second half of the period. The Renaissance is characterized by a cultural movement that was promoted by people who saw classical antiquity, the world of ancient Greece and Rome, as a model to be emulated in their own time. It spread most effectively through the medium of educational reforms taking place in the schools and universities that trained the élite classes, and its values were therefore widely promoted among the powerful and the learned. From Italy the movement spread northwards across the Alps, transforming cultural life not just among the literate minority but also, through their influence, in society as a whole. For the sciences, it meant above all a focus on the philosophical, including the mathematical, traditions and texts of antiquity. "Renaissance" means "rebirth," and the ancient world that was being revived was one that included, besides the architecture of Athens and the poems of Ovid, the physics of Aristotle, the mathematics of Archimedes and the astronomy of Ptolemy. These were not, to be sure, of major concern to most, but among those who took an interest in them, achievement lay in restoring the endeavours of those classical authors. Our first concern, therefore, will be with this "Scientific Renaissance," which will take us from the end of the fifteenth century through to the beginning of the seventeenth.

The second stage can properly be called the "Scientific Revolution" because it is only in the seventeenth century that the dream of improving knowledge of nature by restoring the ways of antiquity began to be replaced by a widespread sense that newly developed knowledge surpassed, rather than merely emulated, ancient achievements. No longer would the way forward be mapped out by recovering what the ancients had supposedly already known.⁸ The gradual acceptance of novelty is a notable element of this story. Even by the end of the century so-called *novatores* (innovators) continued to be criticized in some quarters precisely because they were *not* following the lead of ancient authorities: it was regarded by some as being in rather poor taste. Most of the major names

of the standard Scientific Revolution indeed worked in the seventeenth rather than the sixteenth century. The only undeniably major figure of the sixteenth century is Nicolaus Copernicus, perhaps along with his fellow astronomer Tycho Brahe. Others, such as Kepler or Galileo, produced their most important work after the start of the new century, as did René Descartes, Christiaan Huygens, and Isaac Newton among many others. It was in the seventeenth century that increasing challenges to the scholastic-Aristotelian orthodoxy in philosophy became sufficiently powerful to displace it from its previously secure position. Aristotelian philosophy continued to be taught in the colleges and universities of Europe, but by 1700 it was hedged about with many qualifications, some of them profound. Institutional inertia, due to the presence of Aristotle's writings on many official curricula, helped its remnants to limp a good way into the eighteenth century, but the world had changed: knowledge of nature increasingly implied knowledge of how natural things *worked* and how they could be *used*.