

INTRODUCTION

Investigations of Nature is addressed to students and all readers interested in the study of nature from the invention of the printing press in the mid-fifteenth century through the end of the eighteenth. This time witnessed profound changes in the intellectual and social landscape: voyages of exploration and exploitation tied to technological advances in navigation and warfare led to the rise of European expansion and colonialism; religious unity was broken with huge political, economic, and intellectual consequences; and the new art of printing led to an explosion of information. European voyages inaugurated a global age, when for the first time the history of different continents or geographic areas could no longer be seen in isolation or with at most limited contact and European ships could be found in virtually every harbor, expanding trade and forms of control across the entire globe. This was the time when problems like the determination of longitude at sea, plant studies, and managing new diseases took center stage, and institutions for the promotion and evaluation of knowledge were created.

Studying the investigations of nature over a long time span, a third of a millennium, poses major problems to historians. In some areas developments can best be characterized as an increase of knowledge within a domain, steady or in leaps. Often, however, matters changed at a deeper level. New questions were asked, old ones vanished; new areas of inquiry emerged—such as a mathematical science of motion early in the seventeenth century or the study of electrical phenomena early in the eighteenth—while older ones disappeared. Until the seventeenth century, for example, astrology was a legitimate science relevant to civic life, philosophy, and medicine; by the eighteenth century it had been widely rejected.

During this period forms of communication transformed the world of learning, owing to the transition from manuscript to print, the diffusion of printed images, and the rise of medical, philosophical, and learned journals. Learned societies were created, while social and gender roles were slowly reconfigured, such as the admission or increased presence at the turn of the eighteenth century of instrument makers and surgeons to elite learned societies. Instrument makers moved from anonymity to being buried in Westminster Abbey, next to Isaac Newton (1643–1727), a trajectory comparable to that of artists in Renaissance Italy.

My aim is not to set up an exam for our historical characters and grade them according to how closely their views resemble ours, but to consider the challenges they faced and see the world through their eyes. I privilege the perspective and terminology of my protagonists. For example, the term *mammal* was coined in the mid-eighteenth century, while oxygen was identified and named only a short time later, in the 1770s. Terms like *biology* and *geology* occurred sporadically at the end of our period but became common only in the nineteenth century; therefore I will mostly avoid them in favor of *natural history*, a discipline that included the animal, vegetable, and mineral kingdoms and that retained its unity during the entire period covered here.

Beside the longer chronological scope, *Investigations* presents novel features distinguishing it from comparable works. First, it aims to offer a more comprehensive study of the intellectual map of the time, covering not only the physical and mathematical disciplines but also, and in comparable measure, geography, the study of human and animal bodies, alchemy and chemistry, and natural history, including museums and collections that reflected and shaped contemporary knowledge. Second, it seeks to integrate more closely intellectual pursuits, including the experimental and methodological investigative practices of our protagonists, with social and political issues like the imperial ambitions characterizing European endeavors. Last, it discusses the role of new instruments and devices, and of their makers. Material culture—the art of constructing and handling instruments, from clocks and telescopes to air pumps and Leiden jars—as well as human and animal anatomical preparations played a key role in the investigation of nature. Often those instruments and devices represent and embody a period and the questions posed at the time.

These features lead naturally to my beginning and end points. Johannes Gutenberg's (ca. 1400–1468) printing press with movable type (ca. 1450) inaugurated new forms of communication; images soon adorned printed books, adding a powerful tool to the creation and transmission of knowledge. Around the same time improvements in artillery transformed the battlefield and raised questions in many related areas, while European ships sailed down the African coast and soon reached the Indian Ocean, crossed the Atlantic, and circumnavigated the entire globe.

At the other end point the *Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers* (1751–1772, Encyclopedia, or systematic dictionary of the sciences, arts and crafts), edited by philosopher Denis Diderot (1713–1784) and mathematician Jean-Baptiste le Rond d'Alembert (1717–1783), was the first multiauthored encyclopedia, with eleven volumes of illustrations, representing a new form of communication I shall selectively explore. It covered a wide spectrum of human endeavors, including not only all areas of theoretical knowledge, specifically the mathematical, natural historical, and medical sciences, but

also practical ones, such as architecture, glassmaking, printing, and weaving. The *Encyclopédie* was a huge endeavor providing an invaluable perspective of the intellectual and technological world to the years between the American (1776) and French (1789) Revolutions, before the rise of the steam engine and the Industrial Revolution.

One may be tempted to take the concepts of investigation and nature for granted. In fact, they are complex notions that underwent substantive change during the period I cover, interacting with and shaping each other, their meanings changing as their relationships were reconfigured. For example, Aristotle (384–322 BCE), the ancient Greek philosopher and investigator of nature, argued that nature involved an inner principle of change toward an end: an acorn had an inner principle of becoming an oak, and a heavy object had an inner principle to move toward its proper place, the center of the Earth, which was believed to coincide with the center of the universe. By contrast, the wood with which a carpenter worked did not have an inner tendency to become, say, a bed.

Here I adopt a broader and looser definition of *nature* closer to that employed by Pliny the Elder (23–79 CE), a Roman administrator and scholar who died near Pompeii during the Vesuvius eruption. His *Historia naturalis* (Natural history) included not only plants, animals, and minerals, but also geography. He also discussed human artifacts and the technological devices to investigate nature, as well as mechanical and measuring instruments. English philosopher and statesman Francis Bacon (1561–1626) also wished to include the mechanical arts and especially the implements used to investigate nature in his natural history, but from a different perspective. In the seventeenth century machines that had previously been seen primarily as artifacts, such as automata imitating insects or birds, appeared analogous to natural processes and operations as part of an intellectual project significantly called the mechanical philosophy.

Concepts of nature and methods of investigation show change but also elements of continuity. Whether studying astronomy or the medicinal properties of plants, many scholars were seeking to uncover God's plan for the creation. At a more practical level, navigation and warfare, tied to the rise of European colonialism and the desire to understand and order the natural world, set the investigative agendas across centuries. Problems like the determination of longitude at sea, the study of plants, the trajectory of projectiles, the nature and path of comets, the shock of the torpedo ray, and the chemistry of life occupied the hands and minds of scholars and practitioners across the entire period covered here. They involved European global ambitions, conceptual transformations, and cross-fertilization among fields. At times the answers given varied greatly, highlighting changing

methods and perspectives; at other times they showed surprising continuity, but frequently the same questions remained. These problems will be discussed on multiple occasions in the relevant chapters across the book.

Investigations of Nature is organized in three parts, covering the Renaissance, the Epistemic Revolution, and the Enlightenment, complex labels that I will discuss below. There are advantages in covering a longer time span than usual. By focusing on one period only, one can easily lose perspective of its key characteristics. Contrasting and comparing the intellectual features, experimental practices, and institutional arrangements of different times, we can better appreciate the features of each as well as elements of continuity and discontinuity. Indeed, only by covering a longer time span can the characteristics of each individual period emerge convincingly. I have given equal weight to each period and treated each in its own right, without presenting the Renaissance as a mere recovery of ancient knowledge and a prelude to the Epistemic Revolution (*epistemic* meaning about knowledge, specifically about concepts of nature and its investigation); the Epistemic Revolution, formerly known as the Scientific Revolution, as a transformative time with respect to a caricature of the Renaissance; or the Enlightenment simply as the reception of views put forward during the Epistemic Revolution.

The map of knowledge as well as disciplinary boundaries and configurations changed slowly. Therefore each part has its own structure, inspired by the organization of the knowledge of its own time. I have framed each chapter in a double grid, one chronological, the other thematic. Readers interested in a particular domain can access the work thematically, going through the relevant chapter in each part, such as the history of astronomy or of alchemy-chemistry. Problems were often interconnected, scholars and craftspeople being active in different areas, crossing boundaries and confounding rigid categorizations; we shall encounter several boundary-crossing topics and people, challenging overly strict disciplinary categorizations. In a work of this nature, however, a broadly disciplinary structure is best suited to offer a comprehensive treatment.

Traditionally the Renaissance was seen as the time when the world appeared like a web of sympathies and antipathies stretching from the stars to metal ores under the earth's surface; the Epistemic Revolution as the time of the mechanical philosophy and mechanisms, when most of the world was seen as machinelike; and the Enlightenment as the time privileging relationships over the search for the nature and cause of phenomena, such as gravity or the concept of force. Matters, however, are considerably more complex.

For our purposes, the Renaissance, from circa 1450 to circa 1610, saw dramatic technological transformations in warfare and navigation, the recovery of

ancient knowledge from the Greek and Roman worlds, and a huge increase in the circulation of knowledge thanks to the newly invented printing press with movable type. Observation of the world, whether in geography or astronomy, plants or animals, and visual representations were the hallmarks of this period. The dominant intellectual tradition in this period stemmed from Aristotle and the ancient physician and anatomist Galen (129–ca. 200 CE), though their authority was often challenged.

The Epistemic Revolution, from around 1610 to the 1680s, saw the dethroning of Aristotle and Galen as the leading authorities in philosophy, the investigation of nature, and medicine. A new understanding of nature based on mechanisms and mechanistic explanations became more prevalent. This period witnessed the emergence of new instruments, such as the telescope, the microscope, the pendulum, the barometer, and the air pump. They transformed experimentation, understood as an active intervention for the purpose of investigating nature, and often enabled the establishment of quantitative relations.

Traditionally the old Scientific Revolution ended with the main works by Isaac Newton, *Philosophiae naturalis principia mathematica* (1687, Mathematical principles of natural philosophy) and *Opticks* (1704), seen as crowning achievements of mathematical and experimental investigations. The main issue is not that both works went through several editions in the eighteenth century. As we are going to see, because of their mathematical complexity, methodology, and philosophical outlook, it is more appropriate to see them in a dialogue with the Enlightenment rather than as a seamless final act of an earlier period. Following the example of Newton's *Principia*, from the late 1680s the emphasis shifted from rigid mechanistic explanations to more relational or phenomenological accounts. Scholars routinely worried about the status of their claims: Were their theories and systems capturing nature's own operations and perhaps even God's plan, or were they merely convenient practices devoid of deeper philosophical and religious dimensions?

During the Enlightenment considerable efforts were devoted to standardization in areas as diverse as plant classification, chemical nomenclature, and temperature scale and measurement, in line with concerns for clarity and the search for data that could be meaningfully compared. Quantification, tabulation, and systematization became major concerns. At the same time, social roles changed with the rise of technicians, instrument makers, and surgeons, and occasionally a growing role for women.

After a general introduction, each part opens with a chapter discussing a defining field: geography and navigation characterize the Renaissance as the age of discovery and colonialism; astronomy and optics characterize the Epistemic Revolution as the age of new instruments, such as the telescope; and universal gravity and methodological concerns characterize the Enlightenment as the age of

quantification and systematization—with welcome and unwelcome consequences—and a reflection on the status of our theories.

Each part ends with a brief chapter in which I make explicit my own standpoint and assumptions. In my experience, students can feel overwhelmed by a barrage of unfamiliar names; therefore I have refrained from mentioning historians in the main narrative. However, I have included a brief historiographic guide in which I mention works offering complementary or even different perspectives. My aim is not to apportion praise or blame, but briefly to present some of the main themes and concerns of influential interpretations, with greater emphasis on recent ones. It is instructive for students to appreciate the existence and significance of different approaches and perspectives, even in an introductory work.

It would be impossible in a book of this nature to provide a comprehensive account, and I have been very selective in choosing a few notable sources. The bibliography includes readings at varying levels of difficulty on which I relied and that students may find useful. Inevitably a work of this nature involves many choices; I hope students, colleagues, and interested readers will find them appropriate and justified.