# 1

# INTRODUCTION

## The Age of the New

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This volume of the *Cambridge History of Science* covers the period from roughly 1490 to 1730, which is known to anglophone historians of Europe as the "early modern" era,[1] a term pregnant with expectations of things to come. These things were of course mostly unknown and unanticipated by the Europeans who lived during those years, and had they been asked to give their own epoch a name, they would perhaps have called it "the new age" (*aetas nova*). New worlds, East and West, had been discovered, new devices such as the printing press had been invented, new faiths propagated, new stars observed in the heavens with new instruments, new forms of government established and old ones overthrown, new artistic techniques exploited, new markets and trade routes opened, new philosophies advanced with new arguments, and new literary genres created whose very names, such as "news" and "novel," advertised their novelty.

Some of the excitement generated by this ferment is captured in *Nova reperta* (New Discoveries), a series of engravings issued in Antwerp in the early seventeenth century, after the late sixteenth-century designs of the Flemish painter and draftsman Jan van der Straet (1523–1605).[2] The title page shows numbered icons of the first nine discoveries celebrated in the series: of the Americas, the compass, gunpowder, printing, the mechanical clock, guaiacum (an American wood used in the treatment of the French

[1] Among anglophone historians, this term is used to cover the period between roughly 1500 and 1750; historians writing in Italian, French, and German define the period differently, beginning as early as 1350 (the Italians) and ending as late as 1815 (the Germans). Moreover, depending on national historiographic traditions, period designations such as the Renaissance, the Baroque, or *l'âge classique* are preferred over "early modern": see Ilja Micek, "Die Frühe Neuzeit: Definitionsprobleme, Methodendiskussion, Forschungstendenzen," in *Die Frühe Neuzeit in der Geschichtswissenschaft: Forschungstendenzen und Forschungserträge*, ed. Nada Boskovska Leimgruber (Paderborn: Ferdinand Schöningh, 1997), pp. 17–38.

[2] See Alessandra Baroni Vannucci, *Jan van der Straet detto Giovanni Stradano: Flandrus pictor et inventor* (Milan: Jandi Sapi, 1997), pp. 397–400. Reproductions are on the Web site of the University of Liège, http://www.ulg.ac.be/wittert/fr/flori/opera/vanderstraet/vanderstraet_reperta.html. The original designs date from the 1580s.

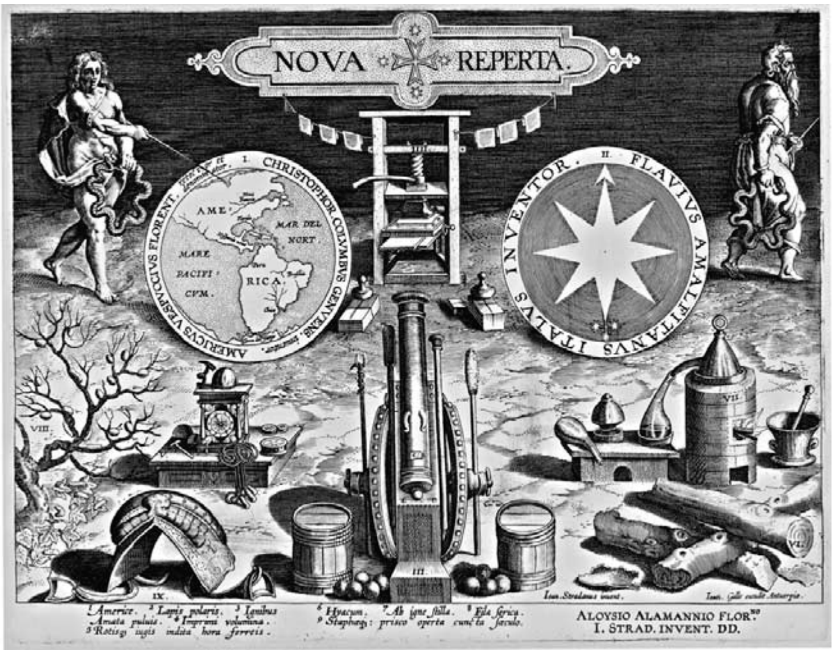


Figure 1.1. *Nova reperta* (New Discoveries). Jan Galle after Joannes Stradanus (Jan van der Straet), ca. 1580, title page of *Nova reperta.* In *Speculum diuersarum imaginum speculatiuarum a varijs viris doctis adinuentarum, atq[ue] insignibus pictoribus ac sculptoribus delineatarum*... (Antwerp: Jan Galle, 1638). Reproduced by permission of the Print Collection, Miriam and Ira D. Wallach Division of Art, Prints and Photographs, The New York Public Library, Astor, Lenox and Tilden Foundations.

disease, or syphilis), distillation, the cultivation of silkworms, and the harnessing of horses (Figure 1.1). Later editions of the series include depictions of the manufacture of cane sugar, the discovery of a method for finding longitude by the declination of the compass, and the invention of the techniques of painting using oil glazes and of copper engraving itself. Although a number of these innovations predated the early modern period, most were closely identified with it, if not because they were the work of early modern Europeans, then because their effects were perceived as having transformed early modern European culture. Certainly, the aggregate effect of the *Nova reperta* engravings, which depict sixteenth-century landscapes, workshops, ships, and domestic spaces, is to portray the period as one of extraordinary fertility, creative ambition, and innovation.

This book concerns one particularly dynamic field of innovation in early modern Europe; for the sake of convenience, this field is usually (albeit anachronistically) subsumed under the portmanteau term "science," taken in its sense (since the nineteenth century) of disciplined inquiry into the phenomena and order of the natural world.[3] This modern category had no single, coherent counterpart in the sixteenth and seventeenth centuries. Indeed, one of the most striking innovations tracked by the chapters in this volume is the gradual emergence of a new domain of inquiry, which had some – but by no means all – of the features of natural science since about 1850. This domain embraced both intellectual and technical approaches and was composed of what had previously been disparate disciplines and pursuits, practiced by people in different professions in different institutions at different sites.

A glance at library classification systems of the period makes this shift vivid. In 1584, a classification system was proposed for the some 10,000 books in the library of French king Henry III, which envisaged separate sections for books on medicine, philosophy (including natural philosophy), mathematics (including optics and astronomy as well as geometry and arithmetic), alchemy, music, and the "vile and mechanical arts," as well as other "arts and sciences," which included theology, jurisprudence, grammar, poetry, and the art of oratory.[4] About a century later, the much-imitated classification of the library of Charles Maurice le Tellier, Archbishop of Reims, lumped together under the rubric of philosophy the following previously disparate fields: natural history, medicine (including anatomy, surgery, pharmacy, and chemistry), the mathematical disciplines (including astronomy and astrology, architecture, and military science and navigation), and the mechanical arts.[5] A new constellation had become visible in the firmament of knowledge, composed of stars that had earlier belonged to quite distinct constellations.

What were these older constellations? To map them accurately, attention must be paid to the sites where the various types of knowledge were cultivated, and by whom, as well as to more formal classifications of knowledge. Names alone (especially when mechanically matched to cognates in modern vernacular languages) are often unreliable guides. The medieval Latin *scientia*, although cognate with the modern English "science," referred to any rigorous and certain body of knowledge that could be organized (in precept though not always in practice) in the form of syllogistic demonstrations from self-evident premises. Under this description, rational theology belonged to *scientia* – indeed, it was the "queen of sciences" – because its premises were the highest and most certain. Excluded, however, were disciplines that studied empirical particulars, such as medical therapeutics, natural history, and

[3] See Andrew Cunningham and Perry Williams, "De-Centring the 'Big Picture': *The Origins of Modern Science* and the Modern Origins of Science," *British Journal for the History of Science*, 26 (1993), 407–32.

[4] Henri-Jean Martin, "Classements et conjonctures," in *Histoire de l'édition française*, ed. Henri-Jean Martin and Roger Chartier, 4 vols. (Paris: Promodis, 1982–6), 1: 429–57, at p. 435.

[5] [Philippe Dubois], *Bibliotheca Telleriana, sive catalogus librorum bibliothecae illustrissimi ac reverendissimi D. D. Caroli Mauritii Le Tellier* (Paris: Typographia Regia, 1693), [Introduction], n.p. On the influence of this classification scheme, see Archer Taylor, *Book Catalogues: Their Varieties and Uses* (Chicago: The Newberry Library, 1957), pp. 157–8.

alchemy, because there can be no absolute certainty about particular phenomena.[6]

The kind of *scientia* that covered topics closer but by no means identical to those treated by modern science was natural philosophy – *philosophia naturalis*, sometimes known as *scientia naturalis* – which studied the material world as it was visible to the senses. Natural philosophy examined change of all kinds, organic and physical, including motion, as well as the principles that produced the phenomena of the heavens (cosmology), the earth's atmosphere (meteorology), and the earth itself (such as minerals, plants, and animals, including human beings). The two topics of plants and animals fell generally under the study of the soul, understood as that which distinguishes living from nonliving beings (see Blair, Chapter 17, this volume). Natural philosophy also addressed questions that would now be seen as metaphysical, such as the nature of space and time and the relation of God to creation (see Garber, Chapter 2, this volume).

Because natural philosophy sought the universal causes of phenomena, it was distinct from natural history, which described naturalia and their particular properties; insofar as this was an object of systematic study, rather than a tool for biblical exegesis or a reservoir for sermon examples and recreational art and literature, it fell under the purview of medicine because some minerals and animals, and many plants, were used in therapeutics. Alchemy had a rather separate existence, not being a university subject, though it was sometimes pursued by physicians because the chemical treatment of substances often aimed at the preparation of medications.

The *scientiae mediae* (or *mathematica media*, "mixed mathematics") differed from natural philosophy in that they dealt with matter considered solely from the standpoint of quantity, without respect to causes. In addition to the pure mathematical disciplines of arithmetic and geometry, mathematics included astronomy and astrology (the two terms were often used interchangeably), optics, harmonics, and mechanics.[7] These disciplines were in turn distinct from the "mechanical arts," which would have included practical applications of mathematical knowledge in fields such as architecture, navigation, clockmaking, and engineering (Figures 1.1 and 1.2).

Because all of these disciplines were conceived as separate pursuits, with their own methods, goals, and widely varying degrees of intellectual and social status, it would have been highly unusual, at least in the late fifteenth century, to find the same person involved in all or most of them. Natural philosophy was part of the university curriculum but was usually taught as

[6] Eileen Serene, "Demonstrative Science," in *The Cambridge History of Later Medieval Philosophy: From the Rediscovery of Aristotle to the Disintegration of Scholasticism, 1100–1600*, ed. Norman Kretzmann, Anthony Kenny, and Jan Pinborg (Cambridge: Cambridge University Press, 1982), pp. 496–517.

[7] William Wallace, "Traditional Natural Philosophy," in *The Cambridge History of Renaissance Philosophy*, ed. Charles B. Schmitt, Quentin Skinner, and Eckhard Kessler with Jill Kraye (Cambridge: Cambridge University Press, 1988), pp. 201–35.


Figure 1.2. *Horologia ferrea* (Iron clocks). Jan Galle after Joannes Stradanus (Jan van der Straet), ca. 1580, from *Nova reperta*. In *Speculum diuersarum imaginum speculatiuarum a varijs viris doctis adinuentarum, atq[ue] insignibus pictoribus ac sculptoribus delineatarum . . .* (Antwerp: Jan Galle, 1638). Reproduced by permission of the Print Collection, Miriam and Ira D. Wallach Division of Art, Prints and Photographs, The New York Public Library, Astor, Lenox and Tilden Foundations.

propadeutic to the higher faculty of medicine, at least at Italian universities, and often by medical men. The *quadrivium* of mathematical sciences (arithmetic, geometry, music, and astronomy) and the *trivium* of the verbal ones (grammar, logic, and rhetoric), which together constituted the seven "liberal arts," would have been taught with varying emphases in the university to prepare students for their studies in philosophy. University-trained physicians would have learned some astrology and some natural history – the latter as part of the study of materia medica – but apothecaries, who belonged to the ranks of merchants, would have been the experts in this area. Similarly, mixed mathematicians who consulted concerning fortifications, hydraulics, horology, mapmaking, and a host of other practical activities tended to work out of artisanal studios or as adjuncts to princely courts rather than as university professors.

Hence early modern career trajectories can often appear to modern eyes at once as dazzlingly diverse and oddly circumscribed: A Renaissance engineer such as Leonardo da Vinci painted, designed buildings and machines, drew maps, and built fortresses and canals. But (despite his curiosity about human anatomy) he would not have treated patients nor (despite his speculative ideas on the nature of water) would he have taught a university class in natural philosophy. The multifaceted "Renaissance man" is to some extent a trick of historical perspective, which creates polymathesis out of what was simply a different classification of knowledge and a different professional division of labor.

Similarly, because modern "science" maps so awkwardly onto early modern natural knowledge, there is some temptation to see the latter as a crazy quilt of mismatched parts seeking – finally – to merge into the new conglomerate recognized in the late seventeenth-century arrangement of books in the Tellier library (or even the nineteenth-century category of "science").[8] Yet the older classifications of knowledge and divisions of labor appeared just as coherent to those who lived them as the modern constellation of natural science does to twenty-first-century readers. The most generally accepted division of human knowledge in premodern Europe parsed it not primarily according to subject matter (e.g., nonliving versus living beings), nor according to methods used (e.g., experimenting in laboratories versus reading books in libraries or classrooms), but rather according to whether it served purposes that were "speculative" (i.e., theoretical), "practical" (i.e., related to leading a good and useful life), or "factive" (i.e., related to the production of things in the arts and trades).[9]

What makes the study of nature during the early modern period so difficult to describe, however, is not so much the gap between this period's classifications of knowledge and ours, nor the cumbersome lists (natural philosophy, natural history, medicine, mixed mathematics, mechanical arts) and coinages ("chymistry," "natural knowledge") that try to bridge that gap, but rather the fact that the gusher of novelty that flooded sixteenth- and seventeenth-century Europe also reconfigured knowledge and careers over the course of the early modern period itself. By the turn of the seventeenth century, there were university professors of medicine who not only wrote treatises on natural philosophy but also contributed to cutting-edge mathematics (Girolamo Cardano, 1501–1576), or who began by teaching mathematics but who moved on (and up) to courtly careers in natural philosophy and commissions in engineering (Galileo Galilei, 1564–1642). University-trained physicians turned to peasants and artisans for instruction (Theophrastus Bombastus von Hohenheim, known as Paracelsus, ca. 1493–1541); artisans themselves set forth natural philosophical theories in print (Bernard Palissy, ca. 1510–ca. 1590). What was studied (and in what combinations), how it was studied, where, and by whom were in remarkable flux during this period.

8 Cunningham and Williams, "De-Centring the 'Big Picture'"; and Sydney Ross, "'Scientist': The Story of a Word," *Annals of Science*, 18 (1962), 65–86.
9 See James A. Weisheipl, "The Classification of the Sciences in Medieval Thought," *Mediaeval Studies*, 27 (1965), 54–90.

These changes often meshed with the enormous political, religious, social, and economic transformations that characterized the early modern era, some of which are alluded to in the title page engraving of *Nova reperta*. The invention and diffusion of printing created new kinds of authors and readers (see Johns, Chapter 15, this volume). The religious movements of the Reformation and Counter-Reformation demanded adjustments in not only what was taught but how (see Feldhay, Chapter 29, this volume). Incessant wars of unprecedented length and scale fed demands for improved military technology (see DeVries, Chapter 14, this volume). These wars, together with frequent episodes of religious persecution, triggered waves of forced migration among scholars and skilled artisans, while competition among courts and wealthy cities opened up possibilities for social advancement to these and other practitioners of natural knowledge (see Moran, Chapter 11, this volume). European commerce expanded dramatically in scope and scale. The mineral wealth brought back from the New World reshaped the European economy, while shiploads of new flora and fauna arriving in European ports from exotic lands stimulated natural history and medicine (see the following chapters in this volume: Eamon, Chapter 8; Findlen, Chapter 19). The geography of changes in natural knowledge closely tracked that of religious, military, and economic developments, beginning in northern Italy in the early sixteenth century, spreading to the prosperous towns of Switzerland and southern Germany by the latter part of the century and subsequently to the Low Countries, and then, by the late seventeenth century, to France and England.[10]

In addition to these interlocking transformations, there were others specific to the learned realm. Perhaps the most far-reaching was the intellectual movement known as humanism: the study of Greek and Roman texts not as timeless contributions to a transhistorical intellectual enterprise, as the philosophical and logical works of Aristotle had been treated in medieval schools and universities, but as works of a particular time and place. Because these texts reflected the languages and cultures of the authors that produced them, in all their historical specificity, they needed to be read with those particularities in mind. Humanists' editions and translations of these texts – both those long known and those newly rediscovered – together with their erudite commentaries on them, dramatically expanded the body of works available to students of nature in the sixteenth and seventeenth centuries, making accessible a variety of philosophical and medical traditions in addition to the Aristotelian and Galenic: Platonism (and neo-Platonism), Stoicism, Skepticism, Epicureanism, and Hippocratism.[11]

10 For some sense of the geographical distribution and varying tempos of these developments, see Roy Porter and Mikuláš Teich, eds., *The Renaissance in National Context* (Cambridge: Cambridge University Press, 1992); and Porter and Teich, eds., *The Scientific Revolution in National Context* (Cambridge: Cambridge University Press, 1992).

11 Jill Kraye, "Philologists and Philosophers," in *The Cambridge Companion to Renaissance Humanism*, ed. Jill Kraye (Cambridge: Cambridge University Press, 1996), chap. 8; and Vivian Nutton,

This proliferation of information and possible approaches to the natural order and human cognition had a great impact on natural inquiry (see the following chapters in this volume: Blair, Chapter 17; Joy, Chapter 3; Garber, Chapter 2).[12] In some areas, the new scholarship led to heated debates with more traditional scholars about the value and interpretation of familiar texts – witness the flurry of attacks on and defenses of Pliny's *Natural History* in the 1490s (see Chapter 19, this volume). More generally, however, the broader range of books available – thanks in large part to printing – together with the humanists' cultivation of an elegant Latin style modeled on that of ancient authors, created new scholarly and literary sensibilities. For many sixteenth-century scholars, educated into such sensibilities, the works of medieval interpreters seemed not so much wrong as old-fashioned, poorly informed, and narrowly conceived. A few of these interpreters gained new life after the middle of the sixteenth century, particularly those, such as Thomas Aquinas, whom the Counter-Reformation Church proposed as the touchstones of philosophical and theological orthodoxy. For the most part, however, medieval commentaries, even standbys such as those of Paul of Venice in logic and philosophy or Jacopo da Forlì in medicine, simply ceased to be reprinted.

Thus, new early modern approaches to natural inquiry should not be seen in the first instance as an attack on the doctrines and methods contained in the works of Aristotle and his medieval Arabic and Latin commentators – an impressive intellectual edifice modern scholars often refer to by the shorthand term "scholasticism." Such attacks, although the stuff of popular historiographic legend – crystallized around heroic figures such as Galileo and Francis Bacon (1561–1626) – were less common than one might gather from the many textbooks on the history of early modern science that embrace, with varying degrees of enthusiasm, the premise of a "Scientific Revolution." More typically, as the chapters in Parts I and III of this volume demonstrate, the process of change was gradual and sporadic, shaped well into the first half of the seventeenth century by serious, widespread, and accepted efforts to accommodate ancient texts to newer methods and discoveries.[13] In this intellectual environment of accommodation rather than wholesale innovation, it comes as no surprise that van der Straet's *Nova reperta*, the initial designs

"Hippocrates in the Renaissance," in *Die Hippokratischen Epidemien: Theorie-Praxis-Tradition*, ed. Gerhard Baader and Rolf Winau (Sudhoffs Archiv, Beiheft 27) (Stuttgart: Franz Steiner Verlag, 1989), pp. 420–39.

12 See Anthony Grafton, "The New Science and the Traditions of Humanism," in Kraye, ed., *Cambridge Companion*, chap. 11; and Anthony Grafton, with April Shelford and Nancy Siraisi, *New Worlds, Ancient Texts: The Power of Tradition and the Shock of Discovery* (Cambridge, Mass.: Belknap Press, 1992).

13 See, for example, Christia Mercer, "The Vitality and Importance of Early Modern Aristotelianism," in *The Rise of Modern Philosophy: The Tension Between the New and Traditional Philosophies from Machiavelli to Leibniz*, ed. Tom Sorrell (Oxford: Clarendon Press, 1993); and Ian Maclean, *Logic, Signs, and Nature in the Renaissance: The Case of Learned Medicine* (New York: Cambridge University Press, 2002).

of which date to the 1580s, privileged as sites of dramatic innovation the mechanical arts rather than textual disciplines such as natural philosophy, theoretical medicine, or even natural history. It was only toward the middle of the seventeenth century that the weight of scholarly opinion – and even then there were many objectors – shifted from gradual, accommodationist strategies to calls for more fundamental change, as more and more voices argued that the old edifice of natural knowledge needed to be torn down and a new one constructed, however unclear the shape of that new edifice might be.

Given the vast transformations that characterized the history of early modern Europe, and the impact of those transformations on the organization of knowledge in both theory and practice, the chapters in this volume, especially those in Part III: "Dividing the Study of Nature," necessarily represent a compromise between early modern and modern categories. Although the aim of Part III is to acquaint readers with the substantive changes that occurred in natural knowledge, neither all of the chapter headings nor their arrangement would have been recognizable to early modern Europeans, even those most abreast of new developments. In order to have made them so, the chapters on "Astronomy" and "Astrology," for example, would have needed to be merged, as would indeed all the chapters relating to mixed mathematics: astronomy/astrology, optics, acoustics (or rather, music), mechanics, and parts of the mechanical arts. There would also have been good historical arguments for combining the chapters on "Medicine" and "Natural History," at least for the earlier part of the period. The title of Chapter 21, "From Alchemy to 'Chymistry'," epitomizes the historiographic problems of trying to fix a moving target – and one that emphatically does not become modern chemistry by the end of the period covered in this volume.[14] Quite apart from the difficulties of finding authors to write about branches of knowledge that have since been split up, with their splinters redistributed elsewhere, many readers would be ill-served by a work that presumed a detailed knowledge of the early modern ways of thinking it was supposed to explain. Hence, although each chapter strives to make clear the place of its topic in early modern schemes of knowledge, we have in some cases separated subjects that would have been combined in those schemes and have occasionally relabeled them.

We would therefore recommend that the chapters in Part III be read in tandem with those in Part II: "Personae and Sites of Natural Knowledge," which describe who was making knowledge where. Some of the scenes described in Part II will be familiar: the professor lecturing in the university lecture hall, or the virtuoso performing an experiment in a scientific academy (see the following chapters in this volume: Shapin, Chapter 6; Grafton, Chapter 10; Moran,

[14] William R. Newman and Lawrence Principe, "Alchemy versus Chemistry: The Etymological Origins of a Historiographic Mistake," *Early Science and Medicine*, 3 (1998), 32–65.

Chapter 11). But others will be less so: the tutor employed by an aristocratic family (see Chapter 6, this volume), the apothecary or herbwoman selling medicinal plant products, exotic or domestic (see Chapter 8, this volume), whole households practicing astronomy or natural history (see the following chapters in this volume: Schiebinger, Chapter 7; Cooper, Chapter 9), or military engineers computing the optimal angle of fortifications (see Chapter 14, this volume). No single rubric, modern or early modern, describes what kind of people they were (by gender, rank, confession, or profession) or what kind of knowledge they were forging. For the sake of convenience, we have tried to use the umbrella terms "students of nature" (or "naturalists" or "natural inquirers") and "natural knowledge," which have some seventeenth-century antecedents but were not recognized by most contemporaries as a comprehensive category for all of these varied activities.

Moreover, the relationship between the disciplines of Part III and the personae and sites of Part II was crosshatched and complex. For example, although a disparate crowd of physicians, engineers, alchemists, astronomers, and even natural philosophers might spend parts of their careers at court, the lecture hall was considerably less permeable. Scholars, master artisans, apprentices, and clients of various social ranks might meet in workshops, cannon foundries, or distilleries, as shown in the densely populated engravings of van der Straet's *Nova reperta* (e.g., the clockmaker's shop of Figure 1.2). Academicians and apothecaries might rub shoulders in the piazza or coffeehouse (see the following chapters in this volume: Eamon, Chapter 8; Findlen, Chapter 12; Johns, Chapter 15); correspondents in an epistolary network might never rub shoulders anywhere and for that reason might enjoy greater freedom to indulge in discussions and debates on specialized topics (see Harris, Chapter 16, this volume). Read side-by-side, the chapters in Parts II and III show that the new associations between fields of knowledge (e.g., between alchemy and natural philosophy, or between engineering and mathematics) were matched by new associations between people in new places: the botanical garden, the anatomy theater, and the metropolitan print shop and bookseller.

These associations were made possible in part by the mobility of many practitioners of early modern knowledge. For some, this mobility was voluntary, as in the case of the English astronomer Edmond Halley's (ca. 1656–1743) voyage to Saint Helena or the German naturalist Maria Sybilla Merian's (1647–1717) expedition to Surinam. For others, it was vocational, as for Jesuit missionaries to China or Peru, or the engineers who traveled from court to court offering their services to build fortifications or ornamental fountains. For still others it was involuntary, as when the Protestant astronomer Johannes Kepler (1571–1630) was forced to leave his teaching post in Catholic Graz or the Dutch natural philosopher Christiaan Huygens (1629–1695) gave up his position as president of the Paris Académie Royale des Sciences after the revocation of the Edict of Nantes in 1685. Whether willed or not, these travels