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Science on the Move: Recent Trends in the History of Early Modern Science[*]

by PAMELA H. SMITH

1. INTRODUCTION

One of the most important developments of the period ca. 1400–1750, which I will call *early modern*, was the rise of a new philosophy, the new experimental science.[1] This used to be understood as a history of European achievement from the Renaissance forward, a universe-changing paradigm shift that defined the modern world. There is no doubt that the growth of modern science forms one of the most significant phenomena of the modern age, affirmed today in the massive public and private funding for research into natural science and medicine. But the question for the historian is, What does this modern phenomenon have to do with the early modern period? The last generation has been an exciting time to come of age in the history of science: the field has definitively emerged from its beginnings in the history of philosophy, intellectual history, and the discrete histories of sciences written by and for their practitioners, to offer answers to

[*]I am grateful to Marty Elsky and Sheila Rabin for inviting me to write this article, and for their patience in receiving it. In writing this essay, I had before me the previous two Recent Trends essays in *Renaissance Quarterly*: Susan Karant-Nunn's admirable "Changing One's Mind: Transformations in Reformation History from a Germanist's Perspective," *Renaissance Quarterly* 58, no. 4 (2005): 1101–27; and Larry Silver's extremely informative "Arts and Minds: Scholarship on Early Modern Art History (Northern Europe)," *Renaissance Quarterly* 59, no. 2 (2006): 351–73.

[1]The term *science* is anachronistic for the early modern period. This is a great problem for historians of early modern science. *Scientia* from antiquity to the eighteenth century often connoted knowledge of causes, and usually meant knowledge that was known for certain and organized propositionally. I use *science*, *natural knowledge*, and *the new philosophy* somewhat interchangeably and imprecisely in this essay. It is a mark of the challenging dynamism of the field of history of early modern science that we are at something of a loss as to what to call the object of our study. The *new philosophy* and "active science" (Francis Bacon's phrase from *The Great Instauration*, 1620), as well as the *new experimental philosophy*, are all terms that were used from ca. 1600–1750 to refer to the innovations in methods of philosophizing that contemporaries perceived going on around them. However, for historians of science the role and definition of modern science is one dimension of our object of study, so it seems artificial not to use the term *science* at times in a self-consciously imprecise and catchall manner.

this question that are more complex, less modern, less triumphal, and less Eurocentric. The full picture is still emerging and does not always cohere neatly (it would not be history if this weren't so), but its dynamism has led to an explosion of interest in early modern science that has far exceeded the bounds of the community of professional historians of science. Over the last thirty years or so, the history of science has expanded its reach in response to new appraisals of science in society at large; to movements within the discipline, such as social history, women's history, and the new cultural history; and to work in the sociology of knowledge that has led to a focus on the practices of knowledge making.

We might date the origins of this sea change to the 1960s, and perhaps emblematically to 1962, when both Thomas Kuhn's *The Structure of Scientific Revolutions* and Rachel Carson's *Silent Spring* appeared.[2] Both fostered a more complex and critical view of science, and since then the history of science has continued to reflect both Kuhn's view of science as social and Carson's unease with the unfettered pursuit of science. Insofar as the history of early modern science is about the early formation of the content and methods of modern science, the narrative naturally shifts as modern science itself continues to develop. But the history of early modern science is no longer only concerned with a protoscientific phase of modern science in which modern concepts, theories, and practices are traced back to an originating point in the so-called Scientific Revolution. Indeed, this is undoubtedly the most significant change in the history of science over the past generation: historians of science are now interested in the uses made of natural knowledge more generally, and in historical attitudes to nature more broadly construed. Paying attention to actors' categories — the terms used by early modern individuals to speak about themselves and their work, as opposed to the present-day categories — has become something of a watchword in the history of science. This has led to a huge expansion in the purview of the historian of science.

One possible definition of science and technology is the interaction of humans with their natural environment and their aspirations to understand it. The history of these interactions and understandings could be taken as the task of the history of science. As historians have begun to take this perspective seriously, the history of science has come to encompass subjects

[2]Thomas Kuhn, *The Structure of Scientific Revolutions* (Chicago, 1962); Rachel Carson, *Silent Spring* (New York, 1962). The history of science had already begun to change in the late 1950s, particularly with the work of Lynn Thorndike, Paolo Rossi, Robert K. Merton, and Edgar Zilsel. Until recently, Merton and Zilsel were largely ignored or read selectively, at least in the Anglophone history of science.

such as the study of vernacular understandings of nature, which can bear little relation to modern scientific concepts, and the emergence of nature as a hegemonic source of intellectual authority, which has great importance for the modern world but contains little that directly bears on the understanding of the cosmos. Moreover, the newer history of science takes much greater account of material life and technical know-how, and in this sense intersects with the histories of technology and medicine. Of course, a budding historian of such an expansive, unified history of science, technology, and medicine — *sci-tech-med*, for short — could quite reasonably ask, what does it exclude?[3] I would argue that exclusion should never be the objective in historiography, but it is useful for the purposes of this essay to divide recent approaches to the history of early modern science into these three overarching strands.

First are studies that trace the early modern development of modern scientific objects, practices, and theories, what we might call the history of protosciences such as astronomy and physics. Such histories no longer take their objects of study as fixed, as they once did in a search for forerunners. The aspirations of this type of history have been articulated by the Max Planck Institute for the History of Science in Berlin: "How did the fundamental scientific concepts — such as number, force, heredity, and probability — and practices — such as experiment, proof, and classification — develop in specific historical contexts? How and why did everyday cultural experiences, such as counting, weighing, collecting, and describing, become specialized scientific techniques? And in what ways did originally local knowledge, devised to solve specific problems, become universalized? These questions form the basis of a theoretically-oriented history of science that seeks to understand the nature of scientific thought and practice as a historical phenomenon, at once dynamic and contingent."[4]

Second are the studies of subjects that used to be seen as anathema to what was considered real science, but that are now viewed as the core of early modern understandings of nature, such as alchemy and astrology. These disciplines possess textual traditions and long disciplinary pedigrees as discrete areas of study, but they also had practical and vernacular dimensions that were very important in early modern Europe.

[3]Historians of science do not generally cover all aspects of human attitudes to, and interaction with, nature, but two stimulating attempts can be found in the essays contained in Lorraine Daston and Fernando Vidal, *The Moral Authority of Nature* (Chicago, 2004); and Lorraine Daston and Michael Stolleis, eds., *Natural Law and Laws of Nature in Early Modern Europe: Jurisprudence, Theology, Moral and Natural Philosophy* (Aldershot, 2008).

[4]Max Planck Institute for the History of Science, mission statement from website, http://www.mpiwg-berlin.mpg.de/en/index.html, accessed 25 July 2008.

Third are the studies of subjects that extend beyond the boundaries of protoscience and even beyond early modern elite modes of knowing nature to consider attitudes to the knowledge of nature conceived more broadly, such as vernacular conceptions of the cosmos. Such conceptions of nature may not have possessed a textual tradition, and must be pieced together by examining vernacular practices and beliefs. The history of women in early modern science might also be included in this strand, in the sense that women engaged in many aspects of natural knowledge, but only some took part in those sciences with long textual and disciplinary traditions.

Obviously, division into these three discrete approaches is somewhat artificial, for these perspectives intersect with each other. The best history of science treats its subject not as a monolithic category or as an inevitable development, but rather understands the objects of its study as contingent phenomena that have changed over time, whether they are astronomy, astrology, or vernacular views of the seasonal cycle. Indeed, very few of the modern objects and modes of knowing nature can be found whole in the early modern period (not to mention nature itself).[5] Thus, even very familiar modern scientific concepts such as experiment, observation, precision, and objectivity, which seem to have early modern analogues and cognates, must be studied for their historicity. This premise underlies the predominant approach today to subjects such as alchemy and astrology.

Not all historians of science would accept the broad view of science as human engagement with nature. However, neither the older approach — the study of the protosciences to understand the development of modern science — nor the newer approach — the study of human engagement with nature more broadly — dominates the history of early modern science at this point. And while there are some critical voices of one or the other approach, most would agree that we historians of science can simultaneously trace the histories of present-day understandings of nature as well as draw attention to the multifarious approaches to and uses made of nature in the past. Indeed, such a plurality of approaches is on view in the third volume of *The Cambridge History of Science* on early modern science.[6] This volume provides a vivid snapshot of the state of the field up to 2006, and thus the present essay will outline general trends in the history of science over the last generation that may be most useful for the multidisciplinary audience of *Renaissance Quarterly*, with special attention to some of the

[5]Lorraine Daston, "The Nature of Nature in Early Modern Europe," *Configurations* 6 (1998): 149–72.

[6]Katharine Park and Lorraine Daston, eds., *The Cambridge History of Science*, vol. 3, *Early Modern Science* (Cambridge, 2006).

newest literature.[7] This essay first surveys the trajectories of three approaches to the history of early modern science over the last generation, examining recent books, and then considers the very broad prospect of technoscience as well as the distributed and collaborative nature of knowledge making. It concludes with one of the most recent and potentially paradigm-shifting trends in the history of science: the view out into the early modern globe, as the history of early modern science finally discovers the world.

2. The History of Protoscience

In the history of protoscience the main approach has been to study the social context of established characters and settings for the new science. This trend was fostered over the years by social history, the new cultural history, and an emphasis on scientific practices. This has greatly increased our knowledge about scientific institutions such as the Royal Society and, to a lesser extent, the Académie Royale des Sciences, the Accademia del Cimento and Accademia dei Lincei, and, lastly (but still too meagerly), the Academia Naturae Curiosorum of the German lands. The research on these societies has included detailed prosopographies of the individual members, an expanded view of the networks of correspondence that preexisted and coexisted with these institutions, a study of their proceedings and diverse interests, and a better understanding of their founding motives and matrices.[8] This work on scientific communities has led to fruitful avenues of research that include

[7]For the individual trying to understand new trends in the history of early modern and modern science, another useful source are the recent Focus sections of the journal of the History of Science Society, *Isis.*

[8]The literature that has appeared in the last twenty or so years on these societies is immense, and has accompanied the publication of the correspondence and proceedings of these societies. To take the Royal Society as an example, A. R. Hall and Marie Boas Hall published in thirteen volumes the correspondence of Henry Oldenburg, Secretary to the Royal Society: *The Correspondence of Henry Oldenburg*, ed. A. Rupert Hall and M. Boas Hall (Madison, 1965–86). Then foundational work on the Royal Society and some of its most prominent members was carried out by Michael Hunter. A selection of his many books gives a sense of the trajectory of this work: *The Royal Society and Its Fellows, 1660–1700: The Morphology of an Early Scientific Institution* (Bucks, 1982); *Establishing the New Science: The Experience of the Early Royal Society* (Suffolk, 1989); Michael Hunter, Antonio Clericuzio, and Lawrence M. Principe, eds., *The Correspondence of Robert Boyle, 1636–1691*, 6 vols. (London, 2001); and Michael Hunter, with contributions by Edward B. Davis, Harriet Knight, Charles Littleton, and Lawrence M. Principe, *The Boyle Papers: Understanding the Manuscripts of Robert Boyle* (Aldershot, 2007). Publication of a similar sort has been done for the Paris Académie Royale des Sciences, for example, first in Roger Hahn, *The Anatomy of a Scientific Institution: The Paris Academy of Sciences, 1666–1800* (Berkeley, 1971); and most recently, in Robert Halleux, *Les publications de l'Académie royale des sciences de Paris (1666–1793)* (Turnhout, 2001).

explorations of sociability and science, both of these societies and of older, more informal groupings such as the republic of letters; of the correspondence networks of individuals particularly interested in the religious, irenic, and material possibilities of natural and technical knowledge, such as that of Nicolas-Claude Fabri de Peiresc (1580–1637), Marin Mersenne (1588–1648), Theóphraste Renaudot (1586–1653), Samuel Hartlib (ca. 1600–62), and Melchisédec Thévenot (ca. 1620–92); of the Jesuits in their overseas missions; and many others.[9] Peter Miller's *Peiresc's Europe* makes clear that much scholarly interest in natural knowledge was part and parcel of the pursuit of intellectual and personal virtue, and that antiquarianism and empiricism were closely related in the republic of letters.[10] Similarly, Adam Mosley's *Bearing the Heavens* shows that the making of astronomical knowledge was dependent on the exchange of letters, books, and instruments, and that it was collaborative, as members traded and calibrated observations, contested timekeeping practices, and argued about the shape of the cosmos and the order of the planets.[11]

At the same time, the sociology of knowledge has made an enormous impact on the history of early modern science, not just in studies of the institutionalization of science in the various scientific academies, but more generally in terms of the relationship of politics and natural knowledge, as well as the interplay of social and intellectual hierarchies with the making of scientific knowledge. The foundational text in this regard for the history of early modern science was Simon Schaffer and Steven Shapin's *Leviathan and the Airpump*.[12] Since then, the work of Bruno Latour and Harry Collins has been particularly influential on ideas about the practice of science and how scientific knowledge is made.[13]

[9]On the Jesuits, see Steven J. Harris, "Confession-Building, Long-Distance Networks, and the Organization of Jesuit Science," *Early Science and Medicine* 1 (1996): 287–318. More generally, see David S. Lux and Harold J. Cook, "Closed Circles or Open Networks? Communicating at a Distance during the Scientific Revolution," *History of Science* 43 (1998): 180–211.

[10]Peter Miller, *Peiresc's Europe: Learning and Virtue in the Seventeenth Century* (New Haven, 2000).

[11]Adam Mosley, *Bearing the Heavens: Tycho Brahe and the Astronomical Community of the Late Sixteenth Century* (Cambridge, 2007).

[12]Simon Schaffer and Steven Shapin, *Leviathan and the Airpump: Hobbes, Boyle, and the Experimental Life* (Princeton, 1985).

[13]See, for example, Bruno Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge, MA, 1987); and Harry M. Collins, *Changing Order: Replication and Induction in Scientific Practice* (London, 1985). See also Jan Golinski's excellent account of recent historiography, *Making Natural Knowledge: Constructivism and the History of Science* (Chicago, 2005).

Interest in the social setting for scientific activities has also inspired numerous studies of the noble court and its role as patron of all things connected to nature: the investigation of natural phenomena, objects of nature and art, curiosities, technological projects, machines, and scientific societies.[14] It has now become clear that noble patronage was crucial to the emergence of new attitudes to nature, including a new view of the value of natural knowledge for commercial and material ends. This interest on the part of territorial governments in nature might be seen, not entirely anachronistically, as the first glimmerings of state sponsorship for science, an important feature of modern society. Noble court society also created new ways of establishing the validity of natural knowledge, for example, in codes of gentlemanly etiquette.[15] Noble interest in the objects of science, such as preserved natural specimens, objects for the burgeoning *Kunstkammern*, territorial and new world maps, and instruments such as telescopes affirmed the potential of natural knowledge to celebrate reputation and establish credit — both of the ruler and of the natural philosopher — to produce commercially valuable and aesthetically pleasing objects, and to open up unknown worlds.[16] These insights into the ways in which noble courts validated new modes of investigating nature have inspired historians of science to study the audiences for the knowledge of nature more generally. Among works that look at the uses made of natural knowledge outside formal institutional and governmental structures is Larry Stewart's *The Rise of Public Science*.[17]

The history of philosophy has also contributed to a reevaluation of some of the most iconic figures of the Scientific Revolution, as a new generation of historians of philosophy, including Gary Hatfield, Dennis Des Chene, Stephen Gaukroger, Susan James, and Daniel Garber, have helped to rewrite the traditional views of René Descartes (1596–1650) and Francis Bacon (1561–1626) as the first moderns. Examination of Descartes's *Treatise on the Passions* (1649), of his correspondence with the Princess Palatine Elisabeth (1618–80) on the passions and the mind, of his

[14]One early survey of court patronage of science was Bruce T. Moran, ed., *Patronage and Institutions: Science, Technology, and Medicine at the European Court, 1500–1750* (Woodbridge, 1991). One of the best-known examples is Mario Biagioli's *Galileo, Courtier: The Practice of Science in the Culture of Absolutism* (Chicago, 1993).

[15]On this subject, see, in particular, Steven Shapin, *A Social History of Truth: Civility and Science in Seventeenth-Century England* (Chicago, 1994).

[16]See most recently Mario Biagioli, *Galileo's Instruments of Credit: Telescopes, Images, Secrecy* (Chicago, 2006).

[17]Larry Stewart, *The Rise of Public Science: Rhetoric, Technology, and Natural Philosophy in Newtonian Britain, 1660–1750* (Cambridge, 1992).

medical work, and of his relationship to practitioners is bringing about a new era in the study of Descartes.[18] Matthew Jones's recent work has contributed to this reexamination. Jones argues that the central concern of his three protagonists — Descartes, Blaise Pascal (1623–62), and Gottfried Wilhelm Leibniz (1646–1716) — was, like other early modern scholars, the philosophical cultivation of the life of virtue, and that they viewed mathematics and natural philosophy as powerful tools for living the virtuous life. In turn, these concerns shaped their study of mathematics and natural philosophy. In arguing that self-cultivation fueled the dynamism in natural and mathematical knowledge in the early modern period, Jones builds on recent work in the history of early modern science, such as that of Mario Biagioli, Lorraine Daston, Simon Schaffer, Steven Shapin, and others, who have shown that etiquette, sociability, and civility were central to developing the new experimental philosophy.[19]

One of the most influential trends in the history of protoscience has been the work emerging from the Max Planck Institute along the lines of their mission to explore "historical epistemology."[20] Jürgen Renn's volume, *Galileo in Context*, Lorraine Daston and Peter Galison's *Objectivity*, Daston's current research project on observation, and M. Norton Wise's edited collection on precision follow this approach, as do recent works on the protophases of scientific theories and concepts, including Peter Dear for physics and Domenico Bertoloni Meli for mechanics, the latter of which focuses on the role of material objects in the transformation of the science of mechanics.[21]

[18]Gary Hatfield, *Descartes and the Meditations* (London, 2003); Dennis Des Chene, *Spirits and Clocks: Organism and Machine in Descartes* (Ithaca, 2001); Stephen Gaukroger, *Descartes, An Intellectual Biography* (Oxford, 1995); Gaukroger, *Francis Bacon and the Transformation of Early-Modern Philosophy* (Cambridge, 2001); Susan James, *Passion and Action: The Emotions in Early Modern Philosophy* (Oxford, 1997); and Daniel Garber, *Descartes Embodied: Reading Cartesian Philosophy through Cartesian Science* (Cambridge, 2001). See also Klaas van Berkel, *Isaac Beeckman (1588–1637) en de mechanisering van het wereldbeeld* (Amsterdam, 1983).

[19]Matthew Jones, *The Good Life in the Scientific Revolution: Descartes, Pascal, and Leibniz* (Chicago, 2006).

[20]Max Planck Institute for the History of Science, mission statement from website, http://www.mpiwg-berlin.mpg.de/en/index.html, accessed 2008.

[21]Jürgen Renn, ed., *Galileo in Context* (Cambridge, 2001); Lorraine Daston and Peter Galison, *Objectivity* (Cambridge, MA, 2007); M. Norton Wise, ed., *The Values of Precision* (Princeton, 1997). See, for example, Peter Dear, *Discipline and Experience: The Mathematical Way in the Scientific Revolution* (Chicago, 1995); and Domenico Bertoloni Meli, *Thinking with Objects: The Transformation of Mechanics in the Seventeenth Century* (Baltimore, 2006).

3. The History of the Pseudosciences

About three decades ago, historians of science began looking at what since the late eighteenth century had often been considered the lunatic fringes of the investigation of nature, most notably, alchemy, astrology, and magic. However, all these subjects possessed long disciplinary histories with both practical and textual components reaching back to antiquity. Perhaps because of both the age and the hybrid nature of these subjects, as well as their status today as countercultural, they became the first levers by which the history of science was expanded beyond the bounds of a protoscientific story.[22] The story of how these subjects, which had been at the center of elite and vernacular understandings of the natural world in the early modern period, became marginalized in the late eighteenth and nineteenth centuries as pseudosciences has not yet been written, but such a history would shed as much light on the organizing discourses of modern culture as it would on the worldview and beliefs of early modern Europe.

Almost forty years ago, Frances Yates published her exhilarating *The Rosicrucian Enlightenment*, which, although it was roundly criticized then and since, was inspirational in its view that supposedly occult activities such as alchemy, astrology, and Rosicrucianism informed the nascent science: in her account, by their influence on the founding goals and members of the Royal Society.[23] Her narrative may have portrayed this influence in an overly conspiratorial manner, but the view that alchemy, astrology, and natural magic impelled the investigation of nature up through the seventeenth century has now become a generally shared consensus among historians of early modern science. Although Yates was very influential in the Anglophone world, Paolo Rossi's work on natural magic and the new philosophy of Francis Bacon actually preceded Yates by quite some time, as did D. P. Walker's quite different *Spiritual and Demonic Magic*.[24] Other historians — both before and after Yates but influenced by social history, such as Charles Webster — also helped articulate the occult and religious

[22]Lynn Thorndike's *A History of Magic and Experimental Science*, 8 vols. (New York, 1923–58) is a very early example. Recent survey volumes are William R. Newman and Anthony Grafton, eds., *Secrets of Nature: Astrology and Alchemy in Early Modern Europe* (Cambridge, MA, 2001), and Lawrence M. Principe, ed., *Chymists and Chymistry: Studies in the History of Alchemy and Early Modern Chemistry* (Sagamore Beach, 2007).

[23]Frances Yates, *The Rosicrucian Enlightenment* (London, 1972).

[24]Rossi's *Francis Bacon: From Magic to Science*, trans. Sacha Rabinovich (London, 1958) first appeared as *Francesco Bacone, dalla magia alla scienza* (Bari, 1957). See also D. P. Walker, *Spiritual and Demonic Magic from Ficino to Campanella* (London, 1958).

roots of the new philosophy.[25] Allen Debus's work on *The Chemical Philosophy* and European Paracelsianism revealed a philosophy of nature — what he called the *chemical philosophy* — that he argued was equal in its influence on the science of astronomy.[26] Foundational texts for the study of alchemy included Walter Pagel's influential studies of Paracelsus and of van Helmont, and Betty Jo Teeter Dobbs's work on Newton's alchemy.[27]

This historical investigation of the pseudosciences has expanded exponentially in recent years to make its influence felt in fields other than the history of science. Through the 1980s and '90s, historians of science continued to focus on the alchemical and astrological activities of established figures in the history of science, such as Robert Boyle and Isaac Newton.[28] As a result of this research, historians of alchemy and chemistry have reached a consensus that the empiricist attitudes and techniques of the new science, such as the experimental method, the development of quantitative aspirations, and the use of precision instruments, were very much shaped by the hands-on, empirical techniques of alchemy and the early modern chemical industries, including mining, smelting, distillation, and the production of medicaments. But Betty Jo Teeter Dobbs and, more recently, William Newman have argued further that the content of the new science — Newton's theory of gravity, the mechanical philosophy, and the theory of atoms and corpuscles — derived as well from alchemy, or *chymistry*, as Newman calls it, to make clear that it was an amalgam of chemistry, alchemy, and the practical chemical industries.

Since the late 1990s, historians of alchemy have begun to enter the expanded territory of the history of science, resuscitating unknown

[25]Charles Webster, *The Great Instauration: Science, Medicine, and Reform 1626–1660* (London, 1975); Webster, *From Paracelsus to Newton: Magic and the Making of Modern Science* (Cambridge, 1982).

[26]Allen Debus, *The Chemical Philosophy: Paracelsian Science and Medicine in the Sixteenth and Seventeenth Centuries* (New York, 1977); see also Debus's still-useful textbook, *Man and Nature in the Renaissance* (Cambridge, 1978).

[27]Walter Pagel, *Das medizinische Weltbild des Paracelsus. Seine Zusammenhänge mit Neuplatonismus und Gnosis* (Wiesbaden, 1962); and Pagel, *Joan Baptista van Helmont, Reformer of Science and Medicine* (Cambridge, 1982). Betty Jo Teeter Dobbs, *The Foundations of Newton's Alchemy: Or, "The Hunting of the Greene Lyon"* (Cambridge, 1975); Dobbs, *The Janus Faces of Genius: The Role of Alchemy in Newton's Thought* (Cambridge, 1991).

[28]William Newman has been especially prolific in showing the foundational nature of alchemy for the new philosophy, and especially for Isaac Newton, in his numerous studies, from his dissertation on the alchemy of the thirteenth-century pseudo-Geber to his most recent book, *Atoms and Alchemy: Chymistry and the Experimental Origins of the Scientific Revolution* (Chicago, 2006).

practitioners and trying to understand what alchemy and the chemical industries meant to those who practiced them.[29] Bruce Moran's textbook *Distilling Knowledge* begins from the premise that practice and the chemical industries, rather than theory, were central to the influence of alchemy on science, while Ursula Klein and Wolfgang Lefevre have examined the central role of the materials employed in the chemical industries.[30] Tara Nummedal has argued that little-known practical alchemists, although they have never been written into the history of protoscience, shaped discourses of fraud, artifice, and nature in early modern European culture more generally.[31]

Because alchemy and chemistry involved hands-on sensory examination of natural materials — alchemists often examined by tasting, smelling, listening, and touching, as well as by looking — historians of alchemy have recently begun an innovative examination of the body and sensory modes of experiencing nature.[32] Another fundamental component of alchemy and chemistry is their empiricism, their manipulation of natural substances by fire and acid. Historians have come to recognize that this trying and testing cannot always be understood from the texts alone, but requires engaging

[29]The work of Carlos Gilly and Didier Kahn, as well as the output of the Center for History of Hermetic Philosophy and Related Currents (Geschiedenis van de Hermetische Filosofie en verwante stromingen) in Amsterdam has expanded our knowledge of alchemical texts and authors immensely. The work of Ursula Klein on apothecaries and technoscience and of Bruce Moran has opened up the world of alchemical practitioners. Pamela H. Smith, *The Business of Alchemy: Science and Culture in the Holy Roman Empire* (Princeton, 1994) considers how alchemy epitomized productive knowledge. Books such as Jost Weyer's *Graf Wolfgang II von Hohenlohe und die Alchemie: Alchemistische Studien in Schloss Weikersheim, 1587–1610* (Sigmaringen, 1992) have made clear the noble patronage of alchemy and a host of studies have followed since then. John T. Young's *Faith, Medical Alchemy, and Natural Philosophy: Johann Moriaen, Reformed Intelligencer, and the Hartlib Circle* (Aldershot, 1999) examines the place of alchemy in schemes of religious and material reform.

[30]Bruce T. Moran, *Distilling Knowledge: Alchemy, Chemistry, and the Scientific Revolution* (Cambridge, MA, 2005); Ursula Klein and Wolfgang Lefevre, *Materials in Eighteenth-Century Science: A Historical Ontology* (Cambridge, MA, 2007).

[31]Tara Nummedal, *Alchemy and Authority in the Holy Roman Empire* (Chicago, 2007).

[32]Lissa Roberts, "The Death of the Sensuous Chemist," *Studies in the History and Philosophy of Science* 26 (1995): 503–29, recounts the rise of the precision balance as a way to replace the bodily techniques and direct sensory engagement with matter used by earlier French chemists. On the body in natural philosophy more generally, see Werner Kutschmann, *Der Naturwissenschaftler und sein Körper: Die Rolle der 'inneren Natur' in der experimentellen Naturwissenschaft der frühen Neuzeit* (Frankfurt am Main, 1986); Simon Schaffer, "Self Evidence," *Critical Inquiry* 18 (1992): 327–62; and Christopher Lawrence and Steven Shapin, eds., *Science Incarnate: Historical Embodiments of Natural Knowledge* (Chicago, 1998).

with natural materials themselves. Historians of chemistry Lawrence Principe and William Newman have begun replicating alchemical practices in an attempt to better understand them. In *Alchemy Tried in the Fire*, Newman and Principe demonstrate that such phrases as the *tree of Diana*, a treelike metallic structure described in early modern texts as growing in a laboratory vessel, and which historians previously considered a symbolic description, has an actual material correlate. Similarly, they have produced a *silica garden* made with potassium silicate and ferric chloride, which was thought in the early modern period to confirm the growth and multiplication of metals by the alchemical art.[33] Their work has given significant insight into the practical nature of many alchemical texts and techniques that previously had been viewed as allegorical descriptions with no real material basis.

Alchemy was an immensely protean field of knowledge in early modern Europe. It was understood on multiple levels: as a productive art, as an esoteric investigation of nature and the human place in the cosmos, and also as giving insight into the vexed subject of the relationship of matter to spirit. It could be read and practiced as religious allegory, relevant to processes of spiritual transformation, even those of creation and resurrection. Like Galenic medicine, it was a capacious and flexible body of knowledge that touched on almost every part of human life and agency, from organic processes of the human body to the growth of plants and metals in the ground, to the production of all the arts necessary to human beings in a post-Fall world. It dealt with everyday processes of transformation — with fermentation and the production of bread and wine, for example — and with the transformations of matter in productive craft knowledge of all kinds; in refining and perfecting; and with economic transformations. Alchemy both embodied and explained these processes, and it often constituted the language in which these vital matters were discussed. Such a window onto multiple domains of early modern culture will continue to bring forth innovative historical studies.

Something of the same trend can be traced in the history of astrology. In the 1970s, Robert Westman examined the close relationship between

[33]William R. Newman and Lawrence Principe, *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry* (Chicago, 2002); and George Starkey, *Alchemical Laboratory Notebooks and Correspondence*, ed. William R. Newman and Lawrence Principe (Chicago, 2004). See H. Otto Sibum, "Experimental History of Science," in *Museums of Modern Science*, ed. Svante Lindqvist, Marika Hedin, and Ulf Larsson (Canton, 2000), who has also replicated experiments from a later period. Recently, see Peter Heering, "The Enlightened Microscope: Reenactment and Analysis of Projections with Eighteenth-Century Solar Microscopes," *British Journal for the History of Science*, 41 (2008): 345–67.

astrology and astronomy, suggesting that astrology and mathematics as they were taught in the universities were the dominant frameworks for questions of planetary movement and ordering at Copernicus's time.[34] Studies in the 1980s and '90s focused on well-known protoscientists, but since the late '90s historians have examined lesser-known and unknown figures. Among the best of these is Anthony Grafton's study of Girolamo Cardano's astrology, which introduces both the centrality and polyvalent nature of astrology.[35] His book, as well as Lauren Kassell's analysis of the astrologer, physician, and alchemist Simon Forman, demonstrate that astrology in the early modern period was central to understanding the relationship of humans to the cosmos.[36] Astrology was integral for understanding one's own body as well as the workings of nature.

4. Expanding the Boundaries of the History of Science

The most fundamental change in the history of science has been the expansion of what might be viewed as science. These expanded territories now range from alchemy, astrology, and natural magic to medicine, midwifery, and technical and how-to writing, such as books of secrets; to all manner of technical knowledge, such as that of medieval cathedral builders and other artisans; to various types of indigenous knowledge systems, such as that of farmers, miners, and metalworkers. The study of the various ways in which people engaged with nature necessitates examining science not as a purely intellectual activity, but as a material and technical activity as well, thus cutting across the artificial boundary between the history of science and the history of technology. The historiographical and disciplinary division of these two areas is one of the most illogical for the study of the early modern period (the other being the separation of the history of science from the history of medicine). These divisions arose in the twentieth century purely as the result of different professional societies and different originating core

[34]See Robert Westman, "The Astronomer's Role in the 16th Century: A Preliminary Study," *History of Science* 18 (1980): 105–47.

[35]Anthony Grafton, *Cardano's Cosmos: The Worlds and Works of a Renaissance Astrologer* (Cambridge, MA, 1999). See also Laura Ackerman Smoller, *History, Prophecy and the Stars: The Christian Astrology of Pierre D'Ailly, 1350–1420* (Princeton, 1994); Sara Schechner Genuth, *Comets, Popular Culture, and the Birth of Modern Cosmology* (Princeton, 1997); Steven vanden Broecke, *The Limits of Influence: Pico, Louvain, and the Crisis of Renaissance Astrology* (Leiden, 2003); and Günther Oestmann, H. Darrel Rutkin, and Kocku von Stuckrad, eds., *Horoscopes and Public Spheres: Essays on the History of Astrology* (Berlin, 2005).

[36]Lauren Kassell, *Medicine and Magic in Elizabethan London* (Oxford, 2005).

audiences and practitioners: natural scientists, engineers, and doctors. Breaking down these boundaries would be a true contribution to scholarship, but doing so would necessitate adopting a way of talking about science that makes clear that what we really mean is something like *technoscience*, or even *techno-medico-science*. The term *technoscience* comes from science studies, which in the last two decades has brought many new perspectives into the history of science, in particular from anthropology, the sociology of knowledge, and material culture studies. Helen Watson-Verran and David Turnbull note that scientific knowledge is heterogeneous: there is no term that "captures the amalgam of place, bodies, voices, skills, practices, technical devices, theories, social strategies and collective work that together constitute technoscientific knowledge/practices."[37]

This kind of history of science would include a whole new cast of characters. The convergence of all these individuals in the process of knowledge making is a challenge for the history of science, for it is very different from the story of important figures (often called geniuses), texts, and theories from which the history of science was just beginning to diverge when I was an undergraduate. It can be difficult to think outside the framework of individual lives, texts, discrete theories, and institutions, but with the models of open-source software creation and Wikipedia now available to us, it is becoming easier to think about knowledge making as collective and as involving the intersection and sometime cooperation of distantly spread groups of people.[38] Such models of technological innovation might in fact be viewed as the norm throughout history, while the models of individual genius, priority disputes, and the patenting of intellectual property may be short-term historical anomalies.

This approach to the history of early modern science emphasizes the plurality and coexistence of various modes of interacting with nature. It has

[37]Helen Watson-Verran and David Turnbull, "Science and Other Indigenous Knowledge Systems," in *Handbook of Science and Technology Studies*, ed. Sheila Jasanoff, Gerald E. Marble, James C. Peterson, and Trevor Pinch (London, 1995), 117. The theme of technoscience has been developed in two special issues of *Perspectives on Science* 13, nos. 1–2 (2005).

[38]The classic study of distributed cognition is Edwin Hutchins, *Cognition in the Wild* (Cambridge, 1995); collaborative knowledge making is emphasized in Lissa L. Roberts, Simon Schaffer, and Peter Dear, eds., *The Mindful Hand: Inquiry and Invention from the Late Renaissance to Early Industrialisation* (Amsterdam, 2007), as well as in the forthcoming book by Chandra Mukerji, *Impossible Engineering: Technology and Territoriality on the Canal du Midi* (Princeton, 2009). See also Pamela H. Smith and Benjamin Schmidt, eds., *Making Knowledge in Early Modern Europe: Practices, Objects, and Texts, 1400–1800* (Chicago, 2008), especially Chandra Mukerji's "Women Engineers and the Culture of the Pyrenees: Indigenous Knowledge and Engineering in Seventeenth-Century France," 19–44.

led to the greater inclusion of women in the story of science. Londa Schiebinger demonstrated that there were plenty of women who produced natural knowledge in the fifteenth and sixteenth centuries, including female patrons of science, artisans, and salon participants, but historians of science had not recognized these activities as part of scientific knowledge-making processes.[39] Throughout the 1990s, Schiebinger, Paula Findlen, and others both continued to expand the boundaries of the discipline and also resuscitated many women who had been excluded from the history of science, such as Laura Bassi, Maria Gaetana Agnesi, and Maria Sybilla Merian, women who had been engaged in areas that could be seen as protoscientific.[40] Francesca Bray's innovative *Technology and Gender* examined clothmaking by women in China and showed how technology produces identity and subjectivity: the modes by which women produced cloth also produced categories of womanhood.[41] In a similar vein, recent work has demonstrated the centrality of gender to views of nature in the early modern period.[42]

In her recent book *Secrets of Women*, Katharine Park shows that gender played a central role in the shaping of anatomy.[43] She brings out the local, specific, and sometimes surprising origins of dissection: the opening of the bodies of female saints and would-be saints and those of mothers' corpses. She argues that because women's bodies were viewed as singular, the uterus

[39]See Londa Schiebinger, *The Mind Has No Sex? Women in the Origins of Modern Science* (Cambridge, MA, 1989).

[40]Paula Findlen, "Science as a Career in Enlightenment Italy: The Strategies of Laura Bassi," *Isis* 84, no. 3 (1993): 440–69; Findlen, "Masculine Prerogatives: Gender, Space, and Knowledge in the Early Modern Museum," in *The Architecture of Science*, ed. Peter Galison and Emily Thompson, 29–57 (Cambridge, 1999); Maria Gaetana Agnesi, *The Contest for Knowledge: Debates over Women's Learning in Eighteenth-Century Italy*, trans. Rebecca Messbarger and Paula Findlen (Chicago, 2005); and Massimo Mazzotti, *Maria Gaetana Agnesi, Mathematician of God* (Baltimore, 2007). See also Deborah Harkness, "Managing an Experimental Household: The Dees of Mortlake and the Practice of Natural Philosophy," *Isis* 88, no. 2 (1997): 247–62; and Alisha Rankin, "Becoming an Expert Practitioner: Court Experimentalism and the Medical Skills of Anna of Saxony (1532–1585)," *Isis* 98, no. 1 (2007): 23–53.

[41]Francesca Bray, *Technology and Gender: Fabrics of Power in Late Imperial China* (Berkeley, 1997).

[42]Carolyn Merchant, *The Death of Nature: Women, Ecology, and the Scientific Revolution* (San Francisco, 1980); and Merchant, *Ecological Revolutions: Nature, Gender, and Science in New England* (Chapel Hill, 1989). More recently, see Londa Schiebinger, *Nature's Body: Gender in the Making of Modern Science* (Boston, 1993); and Katharine Park, "Nature in Person: Medieval and Renaissance Allegories and Emblems," in *The Moral Authority of Nature*, ed. Lorraine Daston and Fernando Vidal, 50–73 (Chicago, 2004).

[43]Katharine Park, *Secrets of Women: Gender, Generation, and the Origins of Human Dissection* (Cambridge, MA, 2006).

so movable and mutable, and generation and the female generative organs so secret and hidden, the female body became the exemplary object of dissection. Only in the sixteenth century, with the ambitious claims of various surgeons and physicians, would men's bodies come to be seen as equally worthy of investigation. It is no coincidence that Andreas Vesalius portrayed himself anatomizing a female corpse on the frontispiece of *De fabrica corporis humanae* (1543): indeed, it was central to Vesalius's presentation of himself as a founder of reformed anatomy. In addition, Park makes clear the coexistence of various kinds of engagement with nature and various models of generation, while at the same time tracing larger narratives about the development of modern scientific attitudes in medical autopsy and dissection. She thereby provides a model of how to write the history of a protoscience in ways that do justice to the contingency of its development and its genesis out of disparate sources.

5. Humanists

In 1966, Alexandre Koyré wrote that humanist erudition was the enemy of science, because humanists were more interested in texts and antiquity than in nature and the progress of knowledge. However, over the last thirty years such a crowd of learned scholars has successfully challenged this claim that his statement now seems incredible. Charles B. Schmitt's contributions on Renaissance Aristotelianism and natural philosophy, as well as the history of universities, changed the study of Renaissance science and scholarship. Brian Copenhaver's work on Renaissance natural philosophy, including Aristotelian, Hermetic, occult, and natural magic, have provided a steady stream of rebuttals to Koyré's view.[44] Anthony Grafton, too, has been prolific in articulating scholarly concerns about natural knowledge in the Renaissance.[45] Horst Bredekamp's *The Lure of Antiquity* shows the potent combination of nature, *technē*, and antiquity for humanists, while the essays in *Historia: Empiricism and Erudition* clarify the important and hitherto-neglected intersections between history, medicine, antiquarianism,

[44]See, for example, Brian Copenhaver, "Did Science Have a Renaissance?" *Isis* 83, no. 3 (1993): 387–407.

[45]Among Grafton's works most relevant to the history of science are *Defenders of the Text: The Traditions of Scholarship in the Age of Science, 1450–1800* (Cambridge, MA, 1991); Grafton with April Shelford and Nancy Siraisi, *New Worlds, Ancient Texts: The Power of Tradition and the Shock of Discovery* (Cambridge, MA, 1992); *Cardano's Cosmos: The Worlds and Works of a Renaissance Astrologer* (Cambridge, MA, 1999); *Leon Battista Alberti: Master Builder of the Italian Renaissance* (Cambridge, MA, 2000); and Grafton with Nancy Siraisi, eds., *Natural Particulars: Nature and the Disciplines in Renaissance Europe* (Cambridge, MA, 2000).

humanist erudition, and the development of empiricism in the early modern period.[46]

Building on recent scholarship in material culture and the history of the book, Ann Blair, Sachiko Kusukawa, Brian Ogilvie, and others illustrate the ways in which humanists employed books, images, reading practices, and patterns of pedagogy to make knowledge in the Renaissance. Ann Blair studies practices of reading and commonplacing, while Sachiko Kusukawa's work on Vesalius's uses of texts, images, and cadavers shows the complex relationship of these different media to each other, in particular during dissections in the anatomy theater.[47] Brian Ogilvie's recent book recounts the construction of natural history in the overlapping activities of humanists and physicians, who simultaneously studied their texts and cultivated practices such as observation, eyewitness testimony, collection, comparison, and cataloguing.[48] In Ogilvie's account, these are not the inevitable developments of a group that finally learns to look at nature for what it is, but a cumulative and contingent process that took four generations to emerge fully. These recent historians' focus on the techniques as well as the texts of humanism gives us a wholly new picture of the place of texts in the Renaissance and provides insight into the development of important knowledge-making practices.

6. Artisans and Practitioners

One of the central components of the traditional narrative of the Scientific Revolution was the development of empiricism and, in particular, the

[46]Horst Bredekamp, *The Lure of Antiquity and the Cult of the Machine*, trans. Allison Brown (Princeton, 1995); Gianna Pomata and Nancy Siraisi, eds., *Historia: Empiricism and Erudition in Early Modern Europe* (Cambridge, MA, 2005); and Nancy Siraisi, *History, Medicine, and the Traditions of Renaissance Learning* (Ann Arbor, 2007).

[47]See Lisa Jardine and Anthony Grafton, "'Studied for Action': How Gabriel Harvey Read His Livy," *Past and Present* 129 (1990): 30–78; Ann Blair, *The Theater of Nature: Jean Bodin and Renaissance Science* (Princeton, 1997); Blair, "Annotating and Indexing Natural Philosophy," in *Books and the Sciences in History*, eds. Marina Frasca-Spada and Nick Jardine, 69–89 (Cambridge, 2000); and Blair, "Reading Strategies for Coping with Information Overload, ca. 1550–1700," *Journal of the History of Ideas* 64 (2003): 11–28; as well as Adrian Johns, "The Physiology of Reading," in *Books and the Sciences in History*, eds. Marina Frasca-Spada and Nick Jardine, 291–314 (Cambridge, 2000); and, more generally, Adrian Johns, *The Nature of the Book: Print and Knowledge in the Making* (Chicago, 1998). See also Sachiko Kusukawa, "From Counterfeit to Canon: Picturing the Human Body, Especially by Andreas Vesalius," preprint 281, Max-Planck-Institut für Wissenschaftsgeschichte (Berlin, 2004).

[48]Brian W. Ogilvie, *The Science of Describing: Natural History in Renaissance Europe* (Chicago, 2006).

experimental method. The contribution of artisans has traditionally been considered crucial to the development of the new method (although scholars did not always agree on the nature of this contribution). Edgar Zilsel made the most important early formulation of this view.[49] Paolo Rossi built upon Zilsel's work in important ways, arguing that artists and technological practitioners in the early modern period formulated the values that informed modern science, among them the progressive and cumulative nature of scientific knowledge; the view that technology is perfectible; and the idea that scientific knowledge consists in knowing how a mechanical device works or is made, rather than knowing the causes, as Aristotle and the scholastics had taught.[50] James A. Bennett has done some of the best work on the role of artisans and practitioners in his studies of practical mathematicians and instrument makers.[51] Others, such as William Eamon, have focused on the integration of empirical goals and values into the new philosophy, while Pamela O. Long in *Openness, Secrecy, Authorship* shows the way in which the mechanical arts came to be seen as an essential part of the process of producing knowledge.[52]

Practitioners of practical mathematics — surveyors, astrologers, gunners, navigators, gaugers, and teachers of the *abbaco* — and the culture of everyday mathematics, especially in the commercial towns of Italy and the German free imperial cities, have garnered much well-deserved attention

[49]Edgar Zilsel, "The Sociological Roots of Science," *American Journal of Sociology* 47 (1942): 544–62; Zilsel, "The Origin of William Gilbert's Scientific Method," *Journal of the History of Ideas* 2 (1941): 1–32. See also Zilsel, *The Social Origins of Modern Science*, ed. Diederick Raven, Wolfgang Krohn, and Robert S. Cohen (Dordrecht, 2000).

[50]Paolo Rossi, *Philosophy, Technology, and the Arts in the Early Modern Era*, trans. Salvator Attanasio (New York, 1970 [published in Italian in 1962]). Others who contributed to this debate are Arthur Clegg, "Craftsmen and the Origin of Science," *Science and Society* 43 (1979): 186–201; A. C. Crombie, "Science and the Arts in the Renaissance: The Search for Truth and Certainty, Old and New," *History of Science* 18 (1980): 233–46; and Crombie, *Styles of Scientific Thinking in the European Tradition*, 3 vols. (London, 1994). See also Pamela H. Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution* (Chicago, 2004), in which I argue that artisans' claims to directly experience nature through bodily labor helped shape new attitudes to nature and epistemology.

[51]See, for example, James A. Bennett, "The Mechanics' Philosophy and the Mechanical Philosophy," *History of Science* 24 (1986): 1–28.

[52]William Eamon, *Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture* (Princeton, 1994); Pamela O. Long, *Openness, Secrecy, Authorship: Technical Arts and the Culture of Knowledge from Antiquity to the Renaissance* (Baltimore, 2001). See also Long, "The Contribution of Architectural Writers to a 'Scientific' Outlook in the Fifteenth and Sixteenth Centuries," *Journal of Medieval and Renaissance Studies* 15 (1985): 265–98; and Eric Ash, *Power, Knowledge, and Expertise in Elizabethan England* (Baltimore, 2004).

recently.[53] The publication of a manuscript composed by the onetime galley oarsman and eventual commander in the Venetian navy, Michael of Rhodes (d. 1445), which records his voyages, his computations for commerce and astrology, as well as his knowledge of shipbuilding, sheds much light on the vernacular use and understanding of mathematics.[54] Parallel to this examination of practical mathematics, much recent work has focused on scientific instruments — portable sundials, compasses, astrolabes, telescopes, and microscopes — and their makers.[55] Instrument-makers and instruments often functioned as intermediaries between mathematicians, natural philosophers, astronomers, artisans, princes, and merchants. As such, they were central to the important matrix in which new attitudes to, and new theories about, nature developed.

In *The Jewel House* Deborah Harkness claims that the kind of practical activity vividly portrayed by Francis Bacon in the *New Atlantis* as the utopian ideal of Salomon's House already existed in the work of sixteenth-century London tradesmen, artisans, medical practitioners, practical mathematicians, and others.[56] Harkness sees the London practitioners as having shaped an urban sociability that laid down a different set of

[53]See, for example, James A. Bennett, "The Challenge of Practical Mathematics," in *Science, Culture, and Popular Belief in Renaissance Europe*, ed. Stephen Pumfrey, Paolo Rossi, and Maurice Slawinski (Manchester, 1991); as well as Bennett's more recent work. See also Stephen Johnston, "Making Mathematical Practice: Gentlemen, Practitioners and Artisans in Elizabethan England," PhD diss., Cambridge University, 1994; Alfred W. Crosby, *The Measure of Reality: Quantification and Western Society, 1250–1600* (Cambridge, 1997); Frances Willmoth, *Sir Jonas Moore: Practical Mathematics and Restoration Science* (Suffolk, 1993); Frank Swetz, *Capitalism and Arithmetic: The New Math of the 15th Century, Including the Full Text of Treviso Arithmetic of 1478* (La Salle, 1989); Warren van Egmond, *Practical Mathematics in the Italian Renaissance: A Catalog of Italian Abbacus Manuscripts and Printed Books to 1600* (Florence, 1980); Richard A. Goldwaithe, "Schools and Teachers of Commercial Arithmetic in Renaissance Florence," *Journal of European Economy and History* 1 (1972): 418–33; and Raffaella Franci and Laura Toti Rigatelli, *Introduzione all'aritmetica mercantile del Medioevo e del Rinascimento* (Urbino, 1982). See also Alexander Marr, *Mathematics and Material Culture in Late Renaissance Italy* (Chicago, 2009).

[54]Michael of Rhodes, *The Book of Michael of Rhodes: A Fifteenth-Century Maritime Manuscript*, ed. Pamela O. Long, David McGee, and Alan M. Stahl (Cambridge, MA, 2008).

[55]See the works of Silvio A. Bedini, especially *Patrons, Artisans, and Instruments of Science, 1600–1750* (Brookfield, 1999); and *Science and Instruments in Seventeenth-Century Italy* (Brookfield, 1994). See also A. Turner, *Early Scientific Instruments: Europe 1400–1800* (London, 1987); and the articles of G. L. E. Turner, e.g., "Mathematical Instrument-Making in London in the Sixteenth Century," in *English Map-making, 1500–1650*, ed. S. Tyacke, 93–106 (London, 1983).

[56]Deborah Harkness, *The Jewel House: Elizabethan London and the Scientific Revolution* (New Haven, 2007).

foundations for the Scientific Revolution than the gentlemanly sociability discussed earlier in this essay. This urban sociability fostered techniques of acquiring, sharing, and judging knowledge that contributed to the development of empiricism. Harkness maintains that there would have been no Scientific Revolution in England without the urban activities of such practitioners. Her book takes up several new approaches to the history of early modern science: a very expansive view of science, a focus on the collaborative dimensions of knowledge making rather than the contributions of a few individuals, and a consideration of the alien-to-us quality of these individuals' activities and their self-perceptions. At the same time Harkness shows that these diverse activities contributed to attitudes essential to the development of science.

These studies of artisans and practitioners have made it clear that one of the central dimensions of the story of early modern science is the relationship between making objects and knowing nature. The intersection in the late fifteenth and early sixteenth centuries between social groups, pedagogical systems, and diverse epistemologies helped create a new mode of gaining knowledge about nature that eventually became central to the new philosophy.

7. Vernacular Conceptions of Nature

In 1971, Keith Thomas published his remarkable *Religion and the Decline of Magic*.[57] This catalog of popular beliefs had much to say about astrology, alchemy, natural magic, and other topics, yet it did not attract much of an academic following among historians of science. If we define science as human interaction with and aspiration to understand the workings of nature, then popular beliefs are certainly part of this history. Carlo Ginzburg's *The Cheese and the Worms* gained more traction among historians of early modern science, perhaps because it was translated into English around the same time that the influence of the new cultural history began to be felt in the history of science.[58] As Thomas's and Ginzburg's works showed, the study of popular conceptions of nature necessitates research that is not solely centered on printed sources; often it must be carried out in archives — Inquisition and other court archives have proven fruitful — and involves studying the traces of practices. A very useful collection of essays that

[57]Keith Thomas, *Religion and the Decline of Magic: Studies in Popular Beliefs in Sixteenth and Seventeenth Century England* (New York, 1971).

[58]Carlo Ginzburg, *The Cheese and the Worms: The Cosmos of a Sixteenth-Century Miller*, trans. John Tedeschi and Anne C. Tedeschi (Baltimore, 1992).

explore the intersection of popular belief and science is *Science, Culture and Popular Belief in Renaissance Europe*, and a few have followed in its path: for example, Florike Egmond, who has researched both the history of early modern crime and popular conceptions of nature.[59]

Traces of practices and beliefs can be discovered in objects and materials as well. Art historians, such as Thomas Raff and Edgar Lein, in their studies of the meanings of bronze, and Michael Cole, in his remarkable work on Benvenuto Cellini (1500–71), have explored the significance of materials employed by artists and the profound, polyvalent meanings that such materials could hold for artisans and their patrons.[60] Similarly, through a study of medieval paint pigments and recipes, Spike Bucklow has explored some of the conceptions of nature that appear to have informed medieval painters.[61]

I have recently begun investigating the vernacular conceptions of fifteenth- and sixteenth-century metalworkers. Generally, metalworkers enter the history of science by way of the practice of assaying, in which precise quantitative measurements were of supreme importance. From at least the Middle Ages, metalworkers who tested the precious metal content of ores and coins used a set of scales enclosed in a glass case to increase accuracy. This assayers' balance and other such instruments became emblematic of the precision sought in scientific laboratories in the seventeenth century. While this was no doubt one important source for new experimental modes

[59]Stephen Pumfrey, Paolo L. Rossi, and Maurice Slawinksi, eds., *Science, Culture and Popular Belief in Renaissance Europe* (Manchester, 1991); Florike Egmond, "Natuurlijke historie en savoir prolétaire," in *Komenten, monsters en muilezels: Het veranderende natuurbeeld en de natuurwetenschap in de zeventiende eeuw*, ed. Florike Egmond, Erick Jorink, and Rienk Vermij, 53–71 (Haarlem, 1999); Egmond and Robert Zwijnenberg, eds., *Bodily Extremities: Preoccupations with the Human Body in Early Modern European Culture* (Burlington, 2003); Egmond and P. G. Hoftijzer, eds., *Carolus Clusius: Towards a Cultural History of a Renaissance Naturalist* (Amsterdam, 2007); Egmond, *Het visboek: De wereld volgens Adriaen Coenen 1514–1587* (Zutphen, 2005).

[60]Thomas Raff, *Die Sprache der Materialien: Anleitung zu einer Ikonologie der Werkstoffe* (Munich, 1994); Edgard Lein, *Ars Aeraria: Die Kunst des Bronzegießens und die Bedeutung von Bronze in der florentinischen Renaissance* (Mainz, 2004); Michael W. Cole, "Cellini's Blood," *Art Bulletin* 81 (1999): 215–35; Cole, *Cellini and the Principles of Sculpture* (Cambridge, 2002); and Cole, "The Medici *Mercury* and the Breath of Bronze," in *Large Bronzes in the Renaissance*, ed. Peta Motture, 129–53 (New Haven, 2003).

[61]Spike Bucklow, "Paradigms and Pigment Recipes: Vermilion, Synthetic Yellows, and the Nature of Egg," *Zeitschrift für Kunsttechnologie und Konservierung* 13 (1999): 140–49; Bucklow, "Paradigms and Pigment Recipes: Natural Ultramarine," *Zeitschrift für Kunsttechnologie und Konservierung* 14 (2000): 5–14; Bucklow, "Paradigms and Pigment Recipes: Silver and Mercury Blues," *Zeitschrift für Kunsttechnologie und Konservierung* 15 (2001): 25–33.

of engaging with nature, I would argue that metalworkers possessed their own vernacular science that underpinned their techniques, a web of correspondences among vermilion, blood, gold, and lizards that can be teased out of artisanal recipes and practices.[62] Such a network of materials and objects suggests that the discussion of metalworkers' practices of precision and experimentation that has dominated historians' accounts of the relationship of metalworking to science will never fully do justice to early modern metalworkers' own understandings of nature.

The increased attention to everyday science and indigenous knowledge systems has called into question the dichotomy between popular and elite, and, following Roger Chartier, historians have begun to view knowledge of nature in early modern Europe as held in common, but employed differently, by the various groups in society.[63] In the wake of this approach, studies of hitherto-unimagined subjects for the history of science have multiplied as historians of science responded to calls for interdisciplinarity and felt the influence of the new cultural history and the sociology of knowledge since the 1980s. Their studies of secrets,[64] wonders and portents,[65]

[62]I began in *The Body of the Artisan* (see n. 50 above) to consider the "vernacular epistemology" of artisans. More recently, see Pamela H. Smith, "Making and Knowing in a Sixteenth-Century Goldsmith's Workshop," in *The Mindful Hand: Inquiry and Invention between the Late Renaissance and Early Industrialization*, ed. Lissa Roberts, Simon Schaffer, and Peter Dear (Amsterdam, 2007), 20–37; and Smith, "'Art' is to 'Science' as 'Renaissance' is to 'Scientific Revolution'? The Problematic Algorithm of Writing a History of the Modern World," in *New Directions in Art History*, ed. James Elkins and Robert Williams, 427–45 (New York, 2008).

[63]Jean Lave, *Cognition in Practice: Mind, Mathematics and Culture in Everyday Life* (Cambridge, 1988); David Brokensha, D. M. Warren, and Oswald Werner, eds., *Indigenous Knowledge Systems* (Washington, DC, 1980); Helen Watson-Verran and David Turbull, "Science and Other Indigenous Knowledge Systems," in *Handbook of Science and Technology Studies*, ed. Sheila Jasanoff, Gerald E. Marble, James C. Peterson, and Trevor Pinch, 115–39 (London, 1995). See also Clifford D. Conner's lively account in *A People's History of Science: Miners, Midwives, and Low Mechanicks* (New York, 2005). Roger Chartier, "Culture as Appropriation," in *Understanding Popular Culture: Europe from the Middle Ages to the Nineteenth Century*, ed. Steven L. Kaplan, 230–53 (Berlin, 1984).

[64]Books of secrets received pioneering attention in William Eamon's *Science and the Secrets of Nature* (see n. 52 above) but much more work is needed on technical treatises, indeed, on technical writing in general, including recipes and didactic literature of all kinds. Recent attention to books of secrets has come from scholars of literature, such as Rebecca Bushnell, especially *Green Desire: Imagining Early Modern English Gardens* (Ithaca, 2003); Alison Kavey, *Books of Secrets: Natural Philosophy in England, 1550–1600* (Urbana, 2007); and Natasha Glaisyer and Sara Pennell, eds., *Didactic Literature in England 1500–1800: Expertise Constructed* (Burlington, 2003).

[65]Lorraine Daston and Katharine Park, *Wonders and the Order of Nature* (Cambridge, MA, 1998).

jokes,[66] natural magic,[67] hybrid objects that demonstrate the powers of nature and art and that are likely to be found in *Kunstkammern*,[68] and visual art and culture have indeed exploded the boundaries of the history of science.[69] In fact, these studies multiplied so prolifically that it seemed by the end of the 1990s that nothing but microhistories remained in the history of early modern science. Could an overarching narrative like that of the Scientific Revolution be discerned in this mass of fascinating particulars? I'll return to this question after discussing one additional new trend.

[66]Paula Findlen, "Jokes of Nature and Jokes of Knowledge: The Playfulness of Scientific Discourse in Early Modern Europe," *Renaissance Quarterly* 43, no. 2 (1990): 292–331; and Findlen, "Between Carnival and Lent: The Scientific Revolution at the Margins of Culture," *Configurations: A Journal of Literature, Science, and Technology* 6 (1998): 243–67.

[67]See especially Penelope Gouk, *Music, Science, and Natural Magic in Seventeenth-Century England* (New Haven, 1999); Paula Findlen, ed., *Athanasius Kircher: The Last Man Who Knew Everything* (New York, 2004); Christine Göttler and Wolfgang Neuber, eds., *Spirits Unseen: The Representation of Subtle Bodies in Early Modern European Culture* (Leiden, 2008); and Paola Zambelli, *White Magic, Black Magic in the European Renaissance* (Leiden, 2007).

[68]The literature on *Kunstkammern* has exploded since the publication of Oliver Impey and Arthur Macgregor, eds., *The Origins of Museums: The Cabinet of Curiosities in Sixteenth- and Seventeenth-Century Europe* (Oxford, 1985). Notable recent contributions include Thomas DaCosta Kaufmann, *The Mastery of Nature: Aspects of Art, Science, and Humanism in the Renaissance* (Princeton, 1993); Paula Findlen, *Possessing Nature* (Berkeley, 1994); Horst Bredekamp, *The Lure of Antiquity* (see n. 46 above); Martin Kemp, "'Wrought by No Artist's Hand': The Natural, the Artificial, the Exotic, and the Scientific in Some Artifacts from the Renaissance," in *Reframing the Renaissance: Visual Culture in Europe and Latin America 1450–1650*, ed. Claire Farago, 117–96 (New Haven, 1995); Ellinoor Bergvelt and Renée Kistemaker, eds., *De wereld binnen handbereik: Nederlandse kunst- en rariteitenverzamelingen, 1585–1735* (Zwolle, 1992); Andreas Grote, ed., *Macrocosmos in Microcosmo: Die Welt in der Stube. Zur Geschichte des Sammelns 1450 bis 1800* (Opladen, 1994).

[69]See Martin Kemp, *The Science of Art: Optical Themes in Western Art from Brunelleschi to Seurat* (New Haven, 1990); Samuel Y. Edgerton, Jr., *The Heritage of Giotto's Geometry: Art and Science on the Eve of the Scientific Revolution* (Ithaca, 1991); Peter Parshall, "Imago contrafacta: Images and Facts in the Northern Renaissance," *Art History* 16 (1993): 554–79; J. V. Field, *The Invention of Infinity: Mathematics and Art in the Renaissance* (Oxford, 1997); Field, *Piero della Francesca: A Mathematician's Art* (New Haven, 2005); Eileen Reeves, *Painting the Heavens: Art and Science in the Age of Galileo* (Princeton, 1997); David Freedberg, *The Eye of the Lynx: Galileo, His Friends, and the Beginnings of Modern Natural History* (Chicago, 2002); Pamela H. Smith, *The Body of the Artisan* (see n. 50 above); and Horst Bredekamp, *Galilei der Künstler: Der Mond, Die Sonne, Die Hand* (Berlin, 2007).

8. Science on the Move: Breaking out of Europe

We come now to what may potentially be the most paradigm-changing trend in the history of science: the very recent attention to commerce and the global development of science in the early modern period. This area has expanded with the growth of global history more generally, but it is also an outgrowth of the emphasis on the transmission and movement of knowledge.[70] In the early modern period, knowledge of nature moved not just geographically, but also epistemically, as knowledge systems of different social and cultural groups intersected. Such movement resulted in new knowledge as well as in new hierarchies of intellectual authority. This epistemic movement of objects, instruments, techniques, and ideas is recognizable all over Europe in the early modern period: as things moved, new knowledge was created. The period from about 1300 on saw increased commerce, production, and consumption throughout the world, and as goods traveled, knowledge moved along with them. This global movement also helped create new knowledge and practices relating to nature. I conclude by considering briefly how the making of knowledge in general frequently depends upon movement.

The commercial and territorial expansion of Europe and the Ottoman Empire and the formation of long-distance trading networks in East and Southeast Asia led to an unprecedented movement of people and of knowledge. European merchants, backed by territorial powers, expanded into the Atlantic, down the coast of Africa, and to the Americas, as well as entered into well-established trading networks in South and Southeast Asia. Knowledge moved along with trade: with individuals as they migrated, or were resettled in new territories, and with sailors, soldiers, and merchants as they pursued trade and war. Knowledge traveled in objects, instruments, manuscripts, and printed books as trade routes opened up and collectors avidly sought rare and beautiful things, and it moved as factors and agents sent back information to the metropolis. Economic historians and art historians have begun to articulate just how much the period depended upon the flow of goods, ideas, and people from outside Europe.[71] Lisa Jardine memorably

[70]For an illuminating recent set of essays on the transmission of knowledge, see Sachiko Kusukawa and Ian Maclean, eds., *Transmitting Knowledge: Words, Images, and Instruments in Early Modern Europe* (Oxford, 2006).

[71]Since the early work of John Brewer and Roy Porter, eds., *Consumption and the World of Goods* (New York, 1994); Rosamond E. Mack, *Bazaar to Piazza: Italian Trade and Islamic Art, 1300–1600* (Berkeley, 2002); Lisa Jardine, *Worldly Goods: A New History of the Renaissance* (New York, 1998); and Jerry Brotton, *The Renaissance Bazaar: From the Silk Road to Michelangelo* (Oxford, 2002), the field has expanded enormously.

remarked that the Renaissance was not as much cultural rebirth as economic miracle.[72] The increased commerce and the exchange of ideas and material that it engendered brought about an efflorescence of cultural production within Europe, and through this, Europe began to define itself — not, at first, in opposition to the East. This flow and interaction of goods and ideas between Eurasian societies was masked until recently by the subsequent period of European dominance that began in the nineteenth century. This realization about the impact of global commerce on the European Renaissance makes clear that changes in the period we call the Renaissance did not develop in isolation and cannot be viewed as the start of a distinctively European modernity.

The history of science has perhaps been more impervious than other areas to thinking in global terms: it was long seen as the most distinctive result of what was understood to be the European Renaissance. Historians saw science and technology as having developed in Europe and diffused outward to the rest of the world. But this picture is changing decisively now. Historians of science have paid much more attention to commerce in the last decade, a step that is beginning to repair one of the most gaping historiographical lacunae in the history of science.[73] Londa Schiebinger's *Plants and Empire*, the essays in *Colonial Botany*, and Antonio Barrera-Osorio's *Experiencing Nature* have all demonstrated that European interest in nature in the New World and in Asia was always inextricably linked to interest in its commercial exploitation.[74]

Harold Cook's *Matters of Exchange* offers a fundamentally new narrative about the practices of acquiring and producing knowledge in the early modern period.[75] He argues that Dutch commerce in natural goods in the

[72]Lisa Jardine, *Worldly Goods* (see n. 71 above).

[73]Robert K. Merton, *Science, Technology and Society in Seventeenth Century England* (Bruges, 1938), in sections titled "Science, Technology and Economic Development," explicitly tied the rise of science to the rise of capitalism, but this section of his book was almost completely ignored, while the link he posited between science and Protestantism raised a storm of scholarship. More recently, see Margaret C. Jacob, *The Cultural Meaning of the Scientific Revolution* (New York, 1988); Margaret C. Jacob and Larry Stewart, *Practical Matter: Newton's Science in the Service of Industry and Empire, 1687–1851* (Cambridge, MA, 2004); Pamela H. Smith and Paula Findlen, eds., *Merchants and Marvels: Commerce, Science and Art in Early Modern Europe* (New York, 2002).

[74]Londa Schiebinger, *Plants and Empire: Bioprospecting in the Atlantic World* (Cambridge, MA, 2004); Londa Schiebinger and Claudia Swan, eds., *Colonial Botany: Science, Commerce, and Politics in the Early Modern World* (Philadelphia, 2005); and Antonio Barrera-Osorio, *Experiencing Nature: The Spanish American Empire and the Early Scientific Revolution* (Austin, 2006).

[75]Harold J. Cook, *Matters of Exchange: Commerce, Medicine, and Science in the Dutch Golden Age* (New Haven, 2007).

East and West Indies was central in the creation of new modes of valuing objects of nature and information about nature. By his account, commercial accumulation and exchange led to new ways of describing, measuring, and valuing objects and information, what he labels *objectivity*. Moreover, the desires and passions that drove this trade led to attempts to locate moral values in nature, with the result that material betterment and human emotions were portrayed as beneficial. This in turn helped lead to Descartes's work on the passions. Cook associates this trend with the philosophical materialism that emerged at the same time, which was seen as dangerous by the opponents of Descartes and Spinoza. Cook demonstrates that many of the values, such as trust, credibility, and plain speech, that historians have associated with the construction of new modes of early modern knowledge making can be seen as emerging from the Dutch commercial world. He also shows that knowledge making in this world was collective and that its main driving force and audience were medical practitioners.[76]

Joseph Needham's massive project on science and civilization in China, begun in 1954, was founded on what were perceived as the differences between Western and Chinese civilizations, and to some extent historians have followed this approach in subsequent work on the Jesuits in China. Recently, however, historians have come to see the history of science in China and Europe as the history of a continual exchange across Eurasia since the ancient Greeks, or earlier.[77] Benjamin Elman's work has transformed the field.[78] George Saliba aims to do the same for astronomy: Saliba views astronomers in the Islamic world and in Europe as having been engaged on the same project during the Renaissance, working with the same set of textual and mathematical tools.[79] We should not be surprised then that Nicolaus Copernicus (1473–1543) gained insight into the

[76]Harold J. Cook made this point forcefully some time ago in "The Cutting Edge of a Revolution? Medicine and Natural History near the Shores of the North Sea," in *Renaissance and Revolution: Humanists, Scholars, Craftsmen and Natural Philosophers in Early Modern Europe*, ed. J. V. Field and Frank A. J. L. James, 45–61 (Cambridge, 1993). See also John V. Pickstone, *Ways of Knowing: A New History of Science, Technology, and Medicine* (Chicago, 2001).

[77]Roger Hart, "On the Problem of Chinese Science," in *The Science Studies Reader*, ed. Mario Biagioli, 189–201 (New York, 1999), critiques the idea that the two civilizations and their sciences should be compared.

[78]See, most recently, Benjamin Elman, *On Their Own Terms: Science in China 1550–1850* (Cambridge, MA, 2005).

[79]George Saliba, *Islamic Science and the Making of the European Renaissance* (Cambridge, MA, 2007).

mathematical problems concerning the motions of the planets from the work of the astronomers at the Maragha observatory, in particular that of Nasir al-Din al-Tusi (d. 1274).[80]

In the history of science in Latin America, Jorge Cañizares-Esguerra's *How to Write the History of the New World* introduced the idea of Creole epistemology to the history of science, challenging those who took a diffusionist approach, and many historians have followed his lead.[81] David Arnold did the same for South Asia in *Science, Technology, and Medicine in Colonial India*, importing the notion of hybridity from subaltern studies.[82] The historian of science Kapil Raj has demonstrated the complex nature of this process in his work on colonial science in South Asia.[83] Just as British historians have begun to understand the ways that Britain and its empire were co-constituted, these historians of science argue that the material and social practices of science did not simply move outward from a metropolitan center, but rather, that science emerged through a complex process of negotiation, assimilation, and coproduction between colonizer and colonized, set in motion by the global encounters of the early modern period.

This new effort to view the history of science through the lens of commerce and movement has demonstrated how much knowledge about natural materials and products depended upon local informants, not just in the Americas, South Asia, and China, but also in Europe. The changes that

[80]Jamil Ragep makes the same point in works such as "Copernicus and His Islamic Predecessors: Some Historical Remarks," *History of Science* 45 (2007): 65–81. Ragep's works lead one to ask whether the revolution in astronomy should be viewed rather as an Islamic-European revolution that took place over a much longer timespan than what we now call the Copernican revolution.

[81]Jorge Cañizares-Esguerra, *How to Write the History of the New World: Histories, Epistemologies, Identities in the Eighteenth-Century Atlantic World* (Palo Alto, 2001). See also Cañizares-Esguerra, *Nature, Empire, and Nation: Explorations of the History of Science in the Iberian World* (Stanford, 2006). Many of the essays in James Delbourgo and Nicholas Dew, eds., *Science and Empire in the Atlantic World* (New York, 2008) show the marks of this approach. See also Marcy Norton, *Sacred Gifts, Profane Pleasures: A History of Tobacco and Chocolate in the Atlantic World* (Ithaca, 2008).

[82]David Arnold, *Science, Technology, and Medicine in Colonial India* (Cambridge, 2001).

[83]See Kapil Raj, "Colonial Encounters and the Forging of New Knowledge and National Identities: Great Britain and India, 1760–1850," in *Nature and Empire,* ed. R. M. MacLeod, 119–34 (Chicago, 2001); and Raj, *Relocating Modern Science: Circulation and the Construction of Knowledge in South Asia and Europe, 1650–1900* (New York, 2007). See generally Roy MacLeod, ed., *Nature and Empire: Science and the Colonial Enterprise* (Chicago, 2001).

took place in early modern knowledge making, then, must be viewed not as the accomplishment of a single group or society, but rather as the absorption and assimilation of information, techniques, and ideas from a wide variety of sources and locales. It bears mentioning, however, that while natural knowledge may have been produced collectively in early modern society, the process of doing so created a new set of identities and hierarchies, especially in colonial contexts. Science in the eighteenth and nineteenth centuries sought to define and to distinguish between peoples, and thereby created social and epistemic hierarchies. I would venture to say that, until recently, this was also seen as part of the work of the historian of science: to determine who belonged in the story of science — that is, who was modern and scientific — and who did not.

9. The Scientific Revolution

The 1990s saw a spate of textbooks on the Scientific Revolution at the same moment that historians of early modern science began to ask whether the Scientific Revolution had really happened at all.[84] On this subject, Katharine Park and Lorraine Daston remark,

> The cumulative force of the scholarship since the 1980s has been to insert skeptical question marks after every word of this ringing three-word phrase, including the definite article. It is no longer clear that there was any coherent enterprise in the early modern period that can be identified with modern

[84]H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry* (Chicago, 1994); Steven Shapin, *The Scientific Revolution* (Chicago, 1996); James R. Jacob, *The Scientific Revolution: Aspirations and Achievements, 1500–1700* (Atlantic Highlands, 1998); Peter Dear, *Revolutionizing the Sciences: European Knowledge and Its Ambitions, 1500–1700* (Princeton, 2001); Paolo Rossi, *The Birth of Modern Science* (Oxford, 2001). Collected volumes include *Reappraisals of the Scientific Revolution*, eds. David Lindberg and Robert Westman (Cambridge, 1990), especially David Lindberg, "Conceptions of the Scientific Revolution from Bacon to Butterfield: A Preliminary Sketch," 1–26; Roy Porter and Mikulás Teich, eds., *The Scientific Revolution in National Context* (Cambridge, 1992); J. V. Field and Frank A. J. L. James, eds., *Renaissance and Revolution: Humanists, Scholars, Craftsmen and Natural Philosophers in Early Modern Europe* (Cambridge, 1993); and *Rethinking the Scientific Revolution*, ed. Margaret J. Osler (Cambridge, 2000). Also useful are survey articles, such as Roy Porter, "The Scientific Revolution: A Spoke in the Wheel?" in *Revolution in History*, ed. Roy Porter and Mikulás Teich, 290–316 (Cambridge, 1986); Reijer Hooykaas, "The Rise of Modern Science: When and Why?" *British Journal for the History of Science* 20 (1987): 453–73; and Andrew Cunningham and Perry Williams, "De-Centering the 'Big Picture': The Origins of Modern Science and the Modern Origins of Science," *The British Journal for the History of Science* 26, no. 4 (1993): 407–32.

> science, or that the transformations in question were as explosive and discontinuous as the analogy with political revolution implies, or that those transformations were unique in intellectual magnitude and cultural significance. Few professional historians of science embrace the more extravagant claims once made by . . . Herbert Butterfield about the world-shaking significance of the Scientific Revolution, as "the real origin both of the modern world and of the modern mentality." Even the canonical texts of the Revolution's heroes — for example, Galileo, Bacon, or Isaac Newton (1642–1727) — appear modern only if read (as they often are) with the greatest selectivity.[85]

No overarching narrative has replaced that of the Scientific Revolution, but there exist many components of a new narrative. They just do not cohere in the seductive way that the triumphalist story did.[86] This is fitting because of the vastness of the subject: a single narrative would not contain the current boundaries of the history of science. Although I do not think such a unified narrative of early modern science is likely (or even desirable) any time soon, it is now possible to inventory some of the strands that compose the new narrative. In early modern Europe, nature increasingly began to function as a resource, both material and intellectual. It provided the matter for production of objects of desire and consumption, and the knowledge of nature began to be regarded as a way to gain social and intellectual authority. Makers of objects — craftspeople, practitioners — who knew nature, and students of natural philosophy — scholars, humanists, physicians — who desired productive knowledge, began to interact in new

[85]Katharine Park and Lorraine Daston, *Early Modern Science* (see n. 6 above), 12–13. Ibid., 13, n. 17, quotes Herbert Butterfield, *The Origins of Modern Science, 1300–1800*, rev. ed. (New York, 1965), 8. Steven Shapin expresses the same sentiment, pragmatically opening his survey of the Scientific Revolution with "There was no such thing as the Scientific Revolution, and this is a book about it."

[86]Can we still use the term *Scientific Revolution*? Well into the second decade of trying to answer this question, the issue of terminology seems less important, as many have come to see *Scientific Revolution* as a serviceable shorthand for that period in which new ideas about nature and the making of natural knowledge were constructed, without at the same time feeling bound to accept the full import of the anachronistic language of *science* and *revolution*. The use of the term *Scientific Revolution* can be compared to the use of *early modern*, which is a useful term if one does not thereby necessarily imply a founding moment of modernity, or as betokening a particular economic and industrial trajectory. *Early modern* can include the globe in a way that *Renaissance* does not. Periodization is simply a heuristic device; the trick is to avoid the teleology that a phrase implies (which may turn out to be impossible, as Randolf Starn opines in "The Early Modern Muddle," *Journal of Early Modern History* 6 no. 3 [2002]: 296-307).

ways and in new settings. Knowledge of nature began to be important to nobles, city fathers, reformers, collectors, and a diverse range of individuals because it seemed to them that nature was bound up with public good, the arts of war, and with religious and intellectual reform.[87] As natural knowledge became increasingly important, it forged new connections among groups, helped create new identities, brought about new kinds of claims to authority and intellectual legitimacy, and gave rise to new ways of thinking about the senses, certainty, and epistemology. At the same time, objects, images, and representations of natural objects proliferated, and these tangible and visible things — instruments, images, and objects — began to matter more. Their physicality and materiality, the knowledge of them and of their workings, and the sensory modes of gaining knowledge about them, came to possess greater persuasive force.

Many of the new approaches to studying nature were launched at the noble court, in conjunction with merchant voyages, and in the medical faculties of universities. It is important to remember, however, that early modern culture did not yet possess a unified sense of the use and significance of natural knowledge. Talking about nature in the early modern period could fall in the realms of politics, religion, commerce, and spiritual transformation, among others. And the importance of the investigation of nature was not yet self-evident in early modern Europe, although various individuals and groups were beginning to claim that it should be.[88]

The changes in attitudes to knowledge about nature in the early modern period are part of a story of the movement of knowledge through European expansion and colonialism and through world trade, in which objects, practices, texts, techniques, and knowledge passed between East and West, with practitioners and techniques often moving ahead of the written

[87]Research on the relationship between science and religion seems to have quickened recently. For example, see Sachiko Kusukawa, *The Transformations of Natural Philosophy: The Case of Philip Melanchthon* (Cambridge, 1995); James Bono, *The Word of God and the Languages of Man: Interpreting Nature in Early Modern Science and Medicine* (Madison, 1995); John Hedley Brooke, *Science and Religion: Some Historical Perspectives* (Cambridge, 1991); Howard Hotson, *Johann Heinrich Alsted, 1588–1638: Between Renaissance, Reformation, and Universal Reform* (Oxford, 2000); Richard G. Olson, *Science and Religion 1450–1900: From Copernicus to Darwin* (Baltimore, 2006); Peter Harrison, *The Bible, Protestantism, and the Rise of Natural Science* (Cambridge, 1998); and Harrison, *The Fall of Man and the Foundations of Science* (Cambridge, 2008).

[88]Katherine Park and Lorraine Daston's "Introduction: The Age of the New," in *Early Modern Science* (see n. 6 above), 1–17, provides a valuable overview of developments in this period.

word.[89] It is a story of an intersection of vernacular and scholarly culture, which brought about a new union of hand and mind, at the same time that a stark distinction came to be drawn between what counted as scientific knowledge and what was relegated to the category of old wives' tales. The construction of new modes of knowledge making about nature was a distributed, collective process, often involving large numbers of anonymous people: medical practitioners in the Americas, Southeast Asian informants, European herb women, artisans, and many others.

It is difficult to recognize this history in the old history of the Scientific Revolution that was centered on the Copernican hypothesis, and which told a story of a change in theory. This account emerged out of the history of ideas, and it, of course, remains a part of the history of science, but we have come to realize that practices and materials — in other words, the engagement with the stuff of nature — has always been part of science, and that the history of science must be integrated with social history, economic history, art history, and the history of technology and medicine. Moreover, while changes in theories of the cosmos are, of course, exceedingly important in the long run, in the period from about 1400 to at least 1650, I believe the real story lies in changing attitudes to nature, to natural knowledge, and to knowledge making. The centrality of alchemy, astrology, and medicine; the technical engagement with nature, commerce, and the movements and intersections of knowledge; as well as the interaction with new environments and new knowledge systems that global movement engendered, have all displaced the account of the changing disciplinary content of astronomy at the heart of the story of science in the early modern period.

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[89]In 1530, corn was already growing in Avila, Spain. In *The Old World and the New*, J. H. Elliott relies on texts to argue that it took about a century for the New World to be assimilated into the Old. That corn was already growing in Spain within forty years of first contact indicates that exchange and assimilation of information, materials, and practices was already much livelier at an early stage than the texts studied by Elliott lead us to believe. Practices, practitioners, and experience moved ahead of the written word, and this indicates the importance of attending to practices as well as to books. On this, see also Chandra Mukerji, "Tacit Knowledge and Classical Technique in Seventeenth-Century France," *Technology and Culture*, 47, no. 4 (2006): 713–33; and Judith Carney, *Black Rice: The African Origins of Rice Cultivation in the Americas* (Cambridge, MA, 2001). Indeed, following the movement of objects and practices may be one way to reconstruct overarching narratives about sci-tech-med in the early modern period, in something of the way that Starn has suggested in "The Early Modern Muddle" (see n. 86 above); and Sanjay Subrahmanyam has advocated in the writing of "connected histories." See Subrahmanyam, *Explorations in Connected History: From the Tagus to the Ganges* (Oxford, 2005); and "Connected Histories: Notes towards a Reconfiguration of Early Modern Eurasia," *Modern Asian Studies* 31, no. 3 (1997): 735–62.