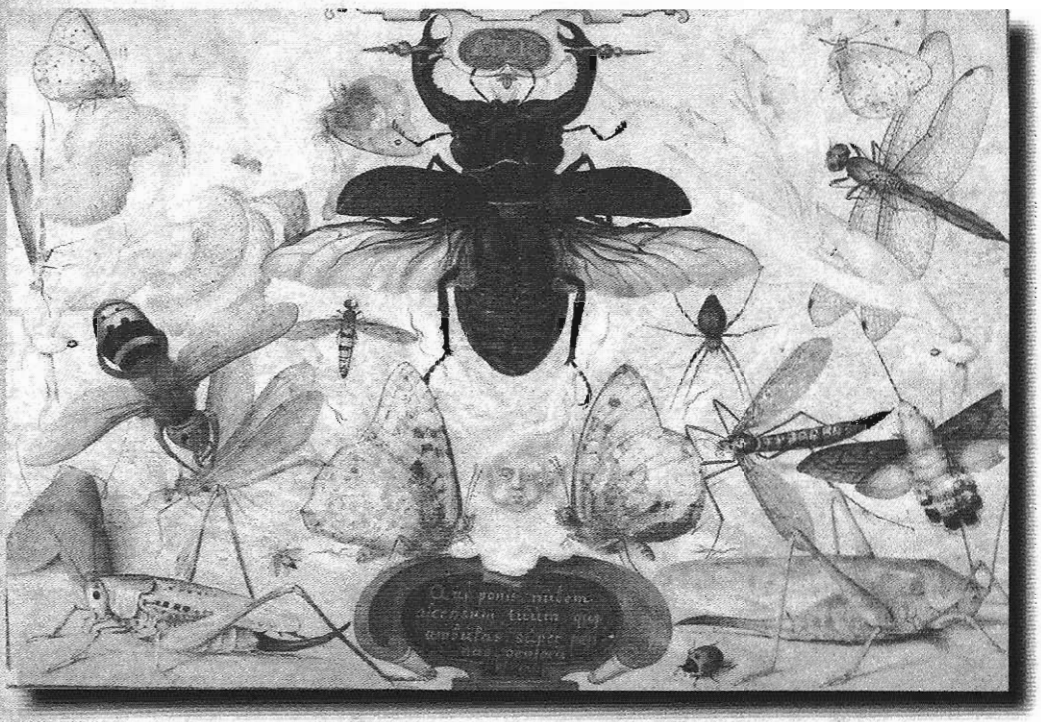
DEBORAH E. HARKNESS

the jewel house



Elizabethan London and the Scientific Revolution

"Enthralling." —*New Yorker*

Published with assistance from the Louis Stern Memorial Fund.

Set in ElectraLH and Trajan type by The Composing Room of Michigan, Inc.
Printed in the United States of America by Vail-Ballou Press, Binghamton, New York.

The Library of Congress has cataloged the hardcover edition as follows:

Harkness, Deborah E., 1965–
The Jewel house : Elizabethan London and the scientific revolution /
Deborah E. Harkness.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-300-11196-5 (cloth : alk. paper) 1. Science—England—London—History
—16th century. 2. Natural history—England—London—History—16th century.
3. Science, Renaissance. 4. London (England)—Social conditions—16th century.
5. London (England)—Social life and customs—16th century. 6. London (England)
—Intellectual life—16th century. I. Title.
Q127.G4H37 2007
509.421'09031—dc22
2007002683

ISBN 978-0-300-14316-4 (pbk. : alk. paper)

A catalogue record for this book is available from the British Library.

This paper meets the requirements of ANSI/NISO Z39.48-1992
(Permanence of Paper). It contains 30 percent postconsumer waste (PCW)
and is certified by the Forest Stewardship Council (FSC).

10 9 8 7 6 5 4 3

A Note About "Science"

Some readers may take issue with my use of the apparently anachronistic collective term *science* to describe the varied Elizabethan interest in nature as it was expressed in London. After all, the *Oxford English Dictionary* does not report *science* — as a term designating the mathematical and physical study of nature — as having come into use until the middle of the nineteenth century.[1] I myself was trained to call the early modern interest in nature *natural philosophy*, since it was not laboratory-based, experimental, palpably modern science. But natural philosophy (I had also been taught) was an elite set of interests, founded in Aristotelian and anti-Aristotelian currents, informed by the new scholarship of humanism, and practiced by gentlemen and scholars with the free time and material resources required to contemplate nature. This definition did not seem to fit the background of the Londoners whose stories appear in this book or to convey their aspirations to put nature to productive and profitable ends.

Science was emerging in sixteenth-century English vernacular usage as an umbrella term to cover scores of such smaller, more easily described interests in specific aspects of the natural world as viticulture, alchemy, mining, and mathematics. From as early in Elizabeth's reign as 1559, when William Cuningham characterized mechanical invention as science, to the end, when Ralph Rabbards signed off on his translation of an alchemical text, "yours in the furtherance of science," the term was used to denote both a study of the natural world and a manipulation of the natural world for productive and profitable ends. Sometimes it was linked explicitly with nature, as when Cuningham identified cosmography as the "most excellent of all [the] other natural science[s]" and Thomas Charnock's *Breviary of Natural Philosophy* listed the names and uses for "all vessels and all instruments . . . in this science" of alchemy. John Securis helpfully defined the term in his *Detection and querimonie of the daily enormi-*

ties and abuses co[m]mited in physick: "science is a habit . . . [a] ready, prompt and bent disposition to do any thing confirmed and had by long study, exercise, and use."[2]

A wide range of Elizabethans used the collective term *science* to describe their interest in properties of the natural world or their efforts to manipulate and control those properties. In works published or republished during the age of Elizabeth, Leonard Digges used the mathematical sciences to identify the contemporary interest in astronomy, astrology, instrumentation, arithmetic, and geometry, as did John Dee, John Blagrave, and William Bourne. The queen voiced her support for "all good sciences and wise and learned inventions," and letters patent were issued under her name for technological experts in the "science" of furnace manufacturing as well as the "science" of glassmaking. Humfrey Baker promised that he had "more ready knowledge in this science" of mathematics than most others in England. Donald Lupton, writing about London, called it a center of all "sciences, arts, and trades," indicating that by the early seventeenth century there were some who were already teasing out the differences between these forms of inquiry and practice. The surgeon George Baker commended Italian and French writers for putting their knowledge of surgical science in the vernacular. His fellow surgeon William Clowes placed medicine and surgery among the sciences and instructed his readers to observe the boundaries that divided science from science. And Francis Bacon looked forward to the time when Englishmen would develop "sciences unknown."[3]

My research uncovered that English vernacular writers on natural history, medicine, mathematics, instrumentation, mechanics, and chemistry used the word *science* throughout the Elizabethan period both as a collective term and to denote individual sciences. The word appears most often among mathematical and medical authors; but it also creeps into the crown's language for the letters patent issued for technological inventions, into the works of popular authors like Donald Lupton who were not writing on science but on the city of London, and even into the queen's official pronouncements on inventions and monopolies. By contrast, very few of the Elizabethans I studied described their work as natural philosophy. Nor did they use any of the other terms that have been suggested to me as more historically sensitive alternatives to the word *science*, including *productive knowledge*, *imitating nature*, or *utility for the common good*. And so I had to make a choice whether to use the collective term at least some of my historical subjects used to describe their efforts or to adopt a term that none of them used but which most historians of science insist is correct and more historically nuanced. I decided to use *science*, just as my subjects did, because this struck me as the least anachronistic alternative.

During the Elizabethan period, residents of London were developing an urban sensibility toward the natural world that historians today might fruitfully call *vernacular science*. As this study shows, vernacular science was based in urban ways of knowing and evaluating nature that came from the densely overlapping social worlds of the City. As such it was distinct from the approach to natural knowledge taught at the university, or the genteel culture shared by gentlemen and gentlewomen at court who might be interested in the natural world. Like vernacular architecture, vernacular science bore some resemblance to the high-culture natural philosophy and intellectual pretensions of both the university and the court, but it had different priorities (observation was privileged over tradition, for example), different forms of expression (sharing experiments was preferred to sharing theoretical knowledge), and different values (dispute and questioning was accepted as a routine aspect of the business of science).

Throughout this book you will find evidence of a contemporary sixteenth-century use of this collective term. References to these instances are indexed under "*science*, contemporary usage of the term." Extrapolating from these examples, I also use *science* throughout as a shorthand collective term to denote Elizabethan Londoners' interest in understanding and exploiting nature even when the individuals in question did not do so. Quentin Skinner has argued that concepts can exist before the word that has come to designate them. This case is a bit more complicated, since the word *science* came into usage, along with some concept of the natural sciences, before we have been willing to admit that it did. This odd state of affairs is evident in the often mentioned, but seldom quoted, earliest definition for science in the *Oxford English Dictionary*. In 1867 W. G. Ward is given credit for coining this particular collective usage for *science*, when he wrote, "We shall . . . use the word 'science' in the sense which Englishmen so commonly give to it; as expressing physical and experimental science, to the exclusion of theological and metaphysical." It would seem that what was common among Englishmen in the nineteenth century was equally common in the sixteenth century.

Similar problems of anachronistic terminology developed when it came time to discuss individual students of nature and to describe their activities in a way that would be consistent and meaningful to a modern reader as well as accurate within an early modern Elizabethan context. Because I found no Elizabethan usage of the term *scientist* to describe a student of nature, I do not use the word unless I am discussing a nineteenth-, twentieth-, or twenty-first-century figure. Instead, I use specific early modern designations—such as *alchemist*, *surgeon*, *apothecary*, and *mathematician*—whenever possible. These terms were in use in the Elizabethan City, based on references I found in London records. Apothe-

caries, surgeons, and physicians were recognized occupational headings, and I also found one City record for an "alchemist," one for a "wizard," and a handful of references to "mathematicians." I use the modern terms *technology, technicians*, and *engineers* to refer collectively to avenues of inquiry and individuals who appeared in Elizabethan records only in connection with very specific activities: "clockmaker," "furnace maker," and "maker of gun-stocks," to give a few examples. There were no contemporary City records that referred to botanists or zoologists, although some Elizabethans did use the word *botanographer* to describe plant hunters and expert gardeners. For ease and consistency I followed one of my subjects, Thomas Moffett, in using the term *naturalist* to describe men and women interested in plants, animals, fossils, and ancient forms of life. When discussing these areas of natural knowledge, I use the term *natural history* even though none of my historical subjects did so.

The passages I have indexed which include contemporary uses of the word *science* are representative of the Elizabethans who used the term but are in no way exhaustive of all the examples that I found in the books and manuscripts of the period. Readers will appreciate that to make an exact catalogue of every Elizabethan use of the word *science* would make this a very different book. So, too, would any attempt to go back to medieval manuscripts and forward to the seventeenth and eighteenth centuries to see how the use of the word *science* changed in earlier and later vernacular English writings. Both of these endeavors would trace historical developments over time, and both would be worthy studies, but my concern here was to describe the study of nature at a particular place and at a particular time.

PRELUDE

London, 1600: The View from Somewhere

Standing on the south bank of the River Thames in 1600 and looking from Southwark to the ancient walled City of London, the viewer would have been struck by four features of her skyline: the monumental, crenellated stone fortress of the Tower of London to the east; the round, half-timbered "O" of the Globe Theater to the south; the truncated spire of St. Paul's cathedral in the west, rising up from the rectangular bulk of the enormous medieval church, still charred from a stroke of lightning that had blown off the top; and the sun glinting off the golden grasshopper that hovered over the smooth stone façade and arched colonnades of Gresham's new Royal Exchange to the north (see Figure 1). These four buildings marked London's distinct skyline and symbolized the political, cultural, religious, and economic power of the metropolis. Elizabethan London was truly the capital of early modern England, the vital, cosmopolitan center of the country's life. Anyone who has struggled to understand the Elizabethan City as a cultural, social, economic, political, or spatial entity will find comfort in the fact that contemporary residents, too, found it both exhilarating and bewildering. "She is grown so great, I am almost afraid to meddle with her," wrote Donald Lupton in 1632, continuing, "she is certainly a great world, there are so many worlds in her."

While London's skyline would have struck any visitor, the real vibrancy of the City — the energy symbolized by the Tower of London, the Globe, St. Paul's, and the Royal Exchange — rested in her people. On her dark, congested streets Londoners lived and worked, argued and worshiped, struggled and thrived. London grew from a small urban center of some 50,000 in 1550 to the second-largest city in Europe by 1600, with more than 200,000 residents. "This city of London is not

only brimful of curiosities, but so popular also that one simply cannot walk along the streets for the crowd," wrote Swiss visitor Thomas Platter in 1599. Elizabethan Londoners were sophisticated and cosmopolitan, living cheek by jowl with immigrants from France, the Netherlands, Spain, Portugal, and Italy. The City's residents included Africans, Ottoman Turks, and Jewish *conversos*. Her foreign population was both a great asset and a great source of anxiety. The immigrants brought new trades like pinmaking and glassmaking, as well as new ideas for waterworks and other engineering projects, but they also increased the stress on already overburdened job and housing markets. Life on the City's streets, below the church spires and under the walkways of the Exchange, was both creative and competitive — the ideal environment for cultural and intellectual change.

Among the bustling crowds were hundreds of men and women who studied and exploited nature. Though they lacked a single building like the Globe Theater to draw the eye of a passing stranger, at street level they made up a recognizable and important feature of London life. These naturalists, medical practitioners, mathematicians, teachers, inventors, and alchemists not only actively studied the natural world; they were also interested in how that study could benefit human lives. During the age of Elizabeth, London nurtured the development of an empirical culture — the culture of the Scientific Revolution. While members of the royal court occupied themselves with threats foreign and domestic, and the universities of Oxford and Cambridge still debated the authority of ancient texts, the residents of London were busy constructing ingenious mechanical devices, testing new medicines, and studying the secrets of nature. There would have been no Scientific Revolution in England without the intellectual vitality present in Elizabethan London, for she provided later scientists with its foundations: the skilled labor, tools, techniques, and empirical insights that were necessary to shift the study of nature out of the library and into the laboratory.

To understand how London helped bring about such a change, it is helpful to return to her streets. St. Paul's cathedral, built in the Middle Ages to signify London's devotion to God, had stood for centuries as the most important landmark in the square-mile center of what was known simply as "the City" (Figure 2). Elizabeth I had launched numerous schemes, including a public lottery, in an effort to rebuild the damaged church. Despite its diminished height, St. Paul's remained the City's ecclesiastical center in 1600. Outside, preachers in open-air pulpits urged throngs of Londoners to repent and mend their ways, raising their voices to be heard over the booksellers and printers who had made the churchyard precincts their home for the past century. Where once it had been the reli-

gious hub of the City, by Elizabeth's reign the cathedral had become the intellectual epicenter of the realm, the source not only of religious debate but also of news sheets, broadsides, and thousands of printed books that spread the ideas of the Renaissance to eager readers. Buyers haunted the stalls outside St. Paul's purchasing used copies of Francis Bacon's *Essays* and first imprints of John Marston's latest play, or picking through bins of cheap old almanacs and star charts for hair-raising illustrations of local wonders like a two-headed calf, and to scoff at once-frightening prognostications made humorous by hindsight. And students of nature flocked there to buy vernacular books on medicine and surgery, imported foreign botanical works, and the mathematical instruments that were often sold along with handbooks that helped explain their use.

There was a high degree of literacy within London, helped along by a system of grammar schools that taught basic skills to City children. Reading, writing, and arithmetic were advantageous in London's competitive markets and in the global trade networks to which they were linked. Sir Thomas Gresham's major gift to the City, the Royal Exchange, was built as a lasting monument to London's position in these markets, and it quickly became the center of economic life in the City. Modeled after Antwerp's famous Bourse, the Royal Exchange housed shops full of expensive luxury items, offices where elite members of the Barber-Surgeons' Company plied their trade, covered walkways where spices, drugs, and cloth were bought and sold, and a grand open courtyard where gossips met and would-be lovers formed romantic liaisons. As the Exchange's popularity grew, market stalls opened up outside the gates, including shops that sold mathematical instruments and hastily erected platforms where itinerant medical practitioners peddled their potions and lotions. One Elizabethan proclaimed that it often seemed as if all of London could be found in the Exchange—lords and ladies, tradesmen and their wives, servants, apprentices, and thieves. Within the Royal Exchange and in the streets surrounding the building you could have heard every language from Arabic to Swedish being spoken by the merchants and foreign immigrants who formed an integral part of London life.

Not all of London's citizens were buying books, but an illiterate person did not lack opportunities to hear the news, make friends with foreigners, or learn of recent economic and political developments at home or abroad. A visit to the Royal Exchange, St. Paul's churchyard, or the theaters on the south bank of the Thames provided any Londoner, literate or illiterate, high or low, foreign or native born, with easy access to news and information. The area around the Globe in Southwark was particularly important as a metropolitan cultural center. New plays by William Shakespeare, Thomas Dekker, and their contemporaries were


LONDON
Scala passuum 5 pedum
80 160 240 320 400 480
Mercers
Grocers
Drapers
Fishmongers
Goldsmiths
Skinners
Merchanttaylors
Haberdashers
Salters
Ironmongers
Vintners
Clothworkers
Islington
Moore fyldes
Spittle fyldes
Moregate
Aldgate
East Smithfyld
S. Katherynes
The tower
Custom howse
Galley kaye
Belinsgate
Olde swann
Shrewsburye howse
The Stilliards
Three cranes
Queens hythe
Broken wharfe
Paules wharfe
Black friers
Bryde well
Whyte friers
The temple
Leicester howse
THAMYS
fluuius
Bankes syde
Lambeth mersh
S. Maryes Overyes
S. Towlyes
South warke
The Beare howse
The play howse
Pietr Vanden Keere fecit 1593
Ioannes Norden Anglus descripsit anno 1593

enacted there and stimulated debate and comment among the audience. Ben Jonson, in and out of prison repeatedly throughout the 1590s, published his satirical send-up of London characters called *Every Man Out of His Humour* in 1600. While the 1599 production of the play at the Globe was warmly received by courtiers traveling down the Thames from Whitehall who enjoyed figuring out which of their friends were being lampooned, the play was seen by some City residents as lacking in both plot and taste. But the area around the Globe also housed a large hospital at St. Thomas's church which was known for its surgical staff, the workshops of several large-scale instrument makers who constructed parish clocks for the City and palace clocks for the royal court, and dozens of immigrant brewers who ran strange distillation and fermentation apparatus that astonished and intrigued the locals.

In 1600 the City's residents still clung tenaciously to London's Roman foundations, the uneven stone walls that encompassed roughly a square mile of territory on the north bank of the Thames. Yet the steady influx of people forced London to push relentlessly outward, and suburban sprawl began to encompass lands that had been gardens (such as the open fields to the west that would in the next centuries be developed into the residential and shopping district Covent Garden), industrial areas (such as the artillery foundries and glasshouses to the northeast of the City walls by the Tower of London), and the lands once held by the now banished Catholic Church. London's rapid expansion underscored her strategic and political importance to the realm, and Elizabeth I took care to treat her capital and its residents with an astute combination of firmness and respect. Yet the City remained difficult to govern due to her cobbled-together nature, the contrast between rich and poor that existed on every street, and her diverse population. While the political ideal of the City was one of peace and harmony, in reality London was a conglomeration of distinct neighborhoods anchored by more than one hundred churches and scores of trade organizations. Each individual and every corporate body wanted to advance their own causes and maintain their hard-won privileges. Overcrowding, the presence of foreign immigrants, poverty, public health crises, and civic unrest made this loose conglomeration contentious and politically explosive. Monarchs, including Elizabeth I, not surprisingly preferred to remain outside the City, maintaining no

Figure 2. Map of London in 1593. Around the margins are the emblems of the twelve major livery companies. A key at the bottom helped readers identify key landmarks, such as the Royal Exchange and St. Paul's. From John Norden's *Speculum Brittaniæ* (1593). Reproduced with the permission of the Henry E. Huntington Library.

official residence within London's walls. Palaces in nearby Westminster and Greenwich put the queen within easy reach of the City in case of serious internal troubles, and within easy reach of the Tower of London in case a foreign invasion was threatened. Such threats were frequent in the half-century before 1600, especially in the years leading up to and away from the great naval battle of the Spanish Armada in 1588, when rumors of impending danger spread like wildfire in the City's streets. Most foreign threats stemmed from the continuing religious antagonisms between Protestant England and her Catholic neighbors Scotland, France, and Spain. In 1600, despite England's victory against Spain, the rumor mill still suggested that there was a Jesuit hiding in every cupboard and a Spanish assassin lurking around every corner. And in fact espionage was a common feature of life in London, with French agents, Italian double-agents, and English spies frequenting the alleys and taverns to gather news and intelligence.

Within these landmark buildings, on the streets around them, behind shopfronts, and upstairs in residences throughout the City, men and women were studying and manipulating nature. This book is about these minor vernacular figures and their small successes, trial-and-error progress, and mundane aspirations. It is about the powerful partnership that existed in London between collaboration and competition, which often led to a heated but amiable discussion of ideas about nature in English rather than a publication of them in Latin. It provides an account of a relatively brief period in London's history and of the men and women who studied the natural world and tried to find better ways to harness its power and control its processes. They pursued this course by examining their own experiences as well as by repeatedly testing and verifying the experiences of their friends and rivals, thus taking steps toward experimentation. In Elizabethan London we can see how students of nature eagerly embraced the new print culture that was available to them but preserved the vibrant manuscript culture of the medieval period in their notebooks and recipe collections. By sketching out this vital world and exploring the ways in which the City of London functioned as a center for inquiry into and debates about nature, I am contributing to an ongoing historical project to situate the work of a small handful of acknowledged scientific geniuses within the densely social communities of practice that surrounded them.

Readers who want to learn more about Isaac Newton, Robert Boyle, Robert Hooke, Edmond Halley, and the other geniuses of the Scientific Revolution — and it is important to do so — may find this book unsatisfying. Here the most well-known figure you will encounter is Francis Bacon (1561–1626). Though not a genius in the sense of Newton or Boyle, he was a visionary. Born and bred in

the age of Elizabeth, he lived just outside London's walls for much of his adult life in the western suburbs of the City. Popularly regarded as the father of modern science for his argument that science should be an organized activity pursued for the benefit of humanity, Bacon was deeply interested in the natural world and her mysterious workings and in *The New Atlantis* (1627) shared his vision for how science could be more functional and productive. Given his fascination with the natural world and his commitment to putting its control into human hands, he should have found the City an exciting and intriguing place. Instead, Bacon found the City's interest in nature deeply troubling. It was too plebeian, too democratic, and too vernacular for his taste. Bacon belonged to a higher level of the social order than did most of the City residents who made medicines, planted botanical gardens, or conducted experiments. How, he wondered, could he transform London's doubtlessly energetic — but to his mind inchoate and purposeless — inquiries into nature into a tool of state that could benefit the commonwealth?

Bacon responded to this question by constructing an ideal house of science — named Salomon's House after the archetype of wisdom in the Bible, King Solomon — that contained the scientific, medical, and technical activities he found most fruitful. The final pages of *The New Atlantis* were dedicated to a fantastic description of Salomon's House and the studies of nature that would take place there. These included efforts to explore the earth's mineral resources, to discover the most fruitful cultivation techniques, and to peruse the heavens with mathematical instruments. The study of the human body would take place in hospitals and anatomical theaters while others struggled to develop new medical cures. In his imaginary house of science, Bacon put all of these activities within a single, hierarchical institution overseen by a single, well-educated man.

In all other respects, however, Salomon's House already existed in the City of London — and Bacon and his contemporaries knew it. Every activity Bacon describes taking place in Salomon's House was already taking place in the City; every goal for seeking out profitable natural knowledge was already being pursued by one or more Londoner. It was not until the end of the seventeenth century, when the memories of the Elizabethan interest in nature had faded and the Royal Society had been established, that people began to look back on Bacon as a prophet of a newly empirical science. And their view has shaped our view. The intervening centuries have not been kind to Elizabethan London's interest in the natural world, and our knowledge of it has been so slight that we, too, saw Salomon's House as a blueprint for what science could *become* rather than a description of what science already *was*. This study puts Bacon's often-cited, seemingly prophetic blueprint for scientific work into its proper context, with the

result that Bacon becomes less of a prophet and more a man in search of a position heading up this remarkable activity.

In the following pages I present multiple views of science as it was practiced during Bacon's life in the City of London. Instead of focusing on a single institution or a particular kind of inquiry into nature, I am interested in the great variety and communal character of London's science — the very qualities that most disturbed Bacon. In Bacon's London, ordinary, foreign- and native-born Londoners engaged in collaboration and competition over matters of natural knowledge with an urban, rather than a gentlemanly, sensibility. The urban sensibility that shaped the study of nature in Elizabethan London emerged from the densely overlapping obligations, ties, and community affiliations that were part of City life during the early modern period. London thrived when its residents embraced complicated partnerships between opposing urban forces — partnerships between private ambitions and public interests, English natives and foreign immigrants, market forces and collegiality, variety and coherence. While gentlemen like Bacon may have seen this urban sensibility as chaotic, it nevertheless shaped how Londoners approached the natural world. Not limited to artists, skilled craftsmen, or members of the City's formal guild and livery company structure, this urban sensibility was shared by most Londoners. City residents belonged to complex social networks that included family members, occupational acquaintances, neighbors, and other friends. In London, like-minded students of nature were drawn together through face-to-face interactions, residential proximity, and a shared desire to exchange books, specimens, techniques, and tools. Through thick description and the mapping of social and intellectual networks among individuals and between communities of practitioners, I sketch a picture of urban science that is striking in both its complexity and its functionality.

London, as a house of science and a prototype of a modern laboratory, worked. Despite the absence of a single institution to order and control it, her urban sensibility helped London practitioners successfully investigate nature, mediate conflicts over knowledge claims, collaborate on projects, expertly adjudicate disputes over methods, train new practitioners, seek financial support from civic and court figures, and negotiate their way through the challenges of studying nature in a crowded urban setting. With respect to science, the urban sensibility shared by Londoners had three important features. First, men and women living in the City expected that their work would be publicly known even if it were not published, because it would be studied and evaluated by other Londoners, especially those involved in similar occupations or trades. Trade associations like the Grocers' Company and the Barber-Surgeons' Company, for example, were

deeply involved in overseeing the quality of medical goods and services produced in their members' shops as well as in policing those individuals outside the company who might impinge on their honor or privileges. Second, London's urban sensibility fostered a belief that residents had specific types of expertise that could and should be exploited to benefit particular individuals and the City as a whole. London was home to all kinds of experts—from ale makers to zookeepers—who could be called on by students of nature to provide specialized assistance in their inquiries. And one did not have to call very far to catch their attention, since London's compact size facilitated exchange and interaction. Third, London's urban sensibility confirmed that work done in collaboration with others was both necessary and desirable in a thriving city. Whether it involved working together with other parish residents to get an unhealthy ditch cleaned out, joining forces to prosecute a particularly egregious offender of civic ordinances, or sharing the responsibilities for policing apprentices with other members of your guild, collaboration was a vital component of getting business done in early modern London.

It was London's urban sensibility, along with new trade networks and her growing population, which made the City an ideal place for new ideas about the natural world to emerge. Shouting to be heard over the din from market stalls on nearly every street, working in cramped backyards over furnaces and smelting ovens, and operating out of storefronts in the Royal Exchange and other merchant neighborhoods, hundreds of men and women of all nationalities engaged in the work of science, medicine, and technology in London. Some were poor immigrants, like "Dutch Hans," a German metalworker who traded his knowledge of the properties of molten lead for beer in a crowded pub near the Globe. Others were fixtures of London's trade organizations, like the Barber-Surgeon George Baker, who extracted teeth, set bones, and performed surgical procedures in his shop at the gates of the Royal Exchange. The Antwerp native Lieven Alaertes and Londoner Thomasina Scarlet established lucrative medical practices in the City, specializing in treating obstetrical and gynecological complaints despite the best efforts of London's College of Physicians to force women out of the medical market. A Venetian merchant and alchemist, Giovan Battista Agnello, operated a dangerous blast furnace in one crowded neighborhood without any complaints from his neighbors, while one of the queen's physicians, the Portuguese converso Roderigo López, was famous, long before accusations that he had tried to poison the queen made him notorious, for seeing patients accompanied by an entourage of African servants.

On London's streets, in her shops, and within the more private enclaves of house and garden, these women and men shared information and expertise with

colleagues and collaborators, argued about knowledge claims and procedures, waged war with competitors, and struggled to come to terms with a confusing and rapidly changing world. In the Middle Ages, ancient authorities like Aristotle and Galen had been the ultimate arbiters in disputes about nature and science. In the sixteenth century, however, such conflicts were more difficult to settle. Nicolaus Copernicus and Johannes Kepler had sketched out a new heaven, and explorers were rapidly charting an entirely new world full of flora and fauna, like the alligator and the tomato, that defied description and challenged the ancient encyclopedias that Elizabethan Londoners still consulted for information. To be in London during the second half of the sixteenth century was to be in a state of heady confusion when it came to natural knowledge and questions of science. Every ship that put in at a London dock might contain new materials that needed to be classified and understood, each new book rolling off the presses at St. Paul's could contain a radical idea about the natural world, and the experiments undertaken in London had, at any moment, the potential to bring long-held beliefs into question.

Yet the Elizabethans, for all their energetic and enthusiastic work studying the natural world, were responsible for only a few scientific breakthroughs. How, then, can their stories help us to understand the Scientific Revolution? Their significance lies not in the elucidation of new formulas or the construction of new cosmological systems, but in the ways that they organized their communities and settled disputes; the value they placed on the acquisition of various literacies (including mathematical, technical, and instrumental literacies); and the practices they developed that led to an increasingly sophisticated hands-on exploration of the natural world. These contributions, I argue, laid the social foundations for the Scientific Revolution in England and did the groundwork that was required so that a man like Boyle knew whom to ask, and what to ask for, when he sought out a man to assist him in his air pump experiments. Every seemingly isolated "great man" of science in the early modern period was surrounded by a "great mass" of workers, assistants, and technicians. In this book I help explain where this great mass came from, and how they developed their skills and knowledge.

By examining six emblematic cases in Elizabethan London, we will survey the social foundations of the Scientific Revolution as they were laid in the City, and come to know the people and the practices that inspired Bacon to conceive Salomon's House. Vivid portraits will emerge of individual practitioners and the challenges they faced when attempting to come to terms with the complexities of the natural world. Networks of intellectual exchange and communities of inquiry can be mapped onto the terrain of Elizabethan London in ways that illuminate the blind alleys and surprising twists and turns taken as science became

the field of knowledge we recognize today. The drive to educate London citizens and make them mathematically literate, for example, created an atmosphere of intense competition as well as fruitful collaboration that was both functional and highly organized, despite its vernacular qualities. And a new emphasis on the hands-on study of nature created demand for technical knowledge about distillation apparatus, medical formulas, grafting techniques, and experimental practices.

The foundations of the Scientific Revolution in Elizabethan London depended on three interrelated social endeavors: forging communities, establishing literacies, and engaging in hands-on practices. In the first two chapters I focus on how communities interested in the natural world coped with the stresses and strains of studying and manipulating nature in an urban environment. Anxieties about new ideas and the influx of foreign practitioners into the City informed how groups negotiated knowledge claims and disputes, and shaped the kind of natural knowledge that was produced. In "Living on Lime Street: 'English' Natural History and the European Republic of Letters" I usher readers into the world of Dutch, French, Flemish, and English naturalists — including botanists, apothecaries, and entomologists — in the downtown neighborhood of Lime Street. Living in close proximity to one another, these friends and business associates enjoyed the face-to-face exchange of ideas as well as correspondence with other naturalists throughout Europe. The Lime Street naturalists and their work were so internationally famous that they caught the attention of an avid student of nature, who was especially interested in plants, the English Barber-Surgeon John Gerard. Gerard lived outside the City's walls, however, and was never able to become a central figure in their cosmopolitan world. So Gerard found another community for his scholarly efforts: readers. Unlike the Lime Street naturalists, Gerard embraced the world of print, and through his published books he began a full-scale assault on Lime Street's credibility and reputation.

Two Barber-Surgeons similarly emphasized the power of the printed word when they tried to expand their role in London's competitive medical marketplace. In "The Contest over Medical Authority: Valentine Russwurin and the Barber-Surgeons" I examine a conflict between foreign and English practitioners that began in the City's streets and ended up in the press. When the German surgeon Valentine Russwurin established a medical stall outside the gates of London's Royal Exchange, he prescribed Paracelsian treatments and therapies to his patients, such as the use of mercury to treat the New World disease syphilis. But important members of the City's Barber-Surgeons' Company were also eager to promote Paracelsian cures and use them in their medical practices. Resentful of Russwurin's success, and anxious about the status of Paracelsian medicine as his

patients began to show serious side effects, a handful of Barber-Surgeons decided to exploit the City's love-hate relationship with foreigners and foreignness. The English Barber-Surgeons began a concerted publishing campaign that polarized London's medical marketplace. Through competition and collaboration, Londoners began to form recognizable communities of expert practitioners during the age of Elizabeth, and successive generations of these communities continued to provide resources and to shape the study of nature well into the seventeenth century.

From a focus on communities, we turn to a focus on literacies. To thrive in the Elizabethan City, Londoners needed to have (or be perceived as having) some special expertise and the most powerful forms of expertise often related to one or more forms of literacy. While we think of literacy as the ability to read and perhaps write, Elizabethan Londoners were eager to gain a broader range of literacies. They wanted to know mathematics—to use arithmetic to keep accounts and geometry to fashion instruments. The ability to manipulate and use such instruments was another kind of literacy, as I explain in Chapter 3. In "Educating Icarus and Displaying Daedalus: Mathematics and Instrumentation in Elizabethan London," we explore how instrument makers, in concert with mathematical educators and civic leaders, put the acquisition of mathematical and instrumental literacy at the forefront of London's educational priorities. Emphasizing the utility of mathematics, and the development of accurate problem-solving skills, these Londoners wanted the City to stand at the vanguard of Europe when it came to the practical application of mathematical knowledge. Though conflicts broke out over whether mathematics was a suitable subject of study for ordinary Londoners, mathematics had the backing of some of the City's most powerful citizens. Their support ensured that the community of mathematicians and technicians thrived, challenging the ancient idea that the life of the mind and the life of the hands must be kept distinct.

In Chapter 4 I take London's concern for multiple forms of literacy and examine the development of an Elizabethan "Big Science" that depended upon citizens with instrumental and technical literacy as well as the financial and political support of the crown and City investors. Elizabeth may not have been a direct source of patronage along the lines of the Holy Roman Emperor Rudolf II or the Medici princes, but she was a shrewd businesswoman who used her secretary of state, William Cecil, and his staff of informants to ensure that England would not be left behind technologically. In "'Big Science' in Elizabethan London" I examine how Elizabeth promoted science by offering inventors monopolies on technical developments, including corn mills, fuel-efficient ovens, water pumps, and methods of processing metals. Competitors resorted to espionage

and theft in order to secure the crown's letters patent, and Cecil brokered disputes over issues of technical expertise and intellectual property, relying on a network of technically literate informants to keep him apprised of the details of each case.

An intense interest in exploring and exploiting the natural world, when coupled with increased mathematical literacy and flourishing technological projects, led to the development of hands-on, experimental practices in Elizabethan London. In the final two chapters I make detailed use of manuscript notebooks to explore how experimental practices were pursued, recorded, and questioned in the City. In "Clement Draper's Prison Notebooks: Reading, Writing, and Doing Science" I focus on the manuscripts kept by an Elizabethan merchant imprisoned for debt. Like the illustrious Francis Bacon, Draper was a visionary, but for him the ideal intellectual community was a commonwealth of experimental knowledge where practitioners shared ideas and experiments irrespective of wealth, class, or university training. Draper's notebooks illuminate how elastic the sense of community could be in a city like London, and how this elasticity made even the most humble contributions potentially valuable in the study of nature. Recording every snippet of text and experimental lore that came his way in the King's Bench prison, Draper's notebooks clarify how writing was itself a valuable form of work during the early days of experimental culture.

We end by accompanying Elizabethan London's most curious student of nature, Hugh Plat, as he amassed an enormous amount of experimental information from City residents. For Plat, London was a "jewel house" of experimental expertise, a treasure trove of natural knowledge, and he saw himself as the lapidary responsible for testing, polishing, and authoritatively recounting the best examples of this work for future generations. In "From the Jewel House to Salomon's House'" I compare Plat's vernacular approach to experimental practice and natural knowledge with that of Francis Bacon. Plat believed that all classes should participate in science, and he valued his grocer's opinions on the virtues of plants as highly as he did a university-educated botanist. Both deserved a place in London's jewel house of science, provided that Plat could verify and test their information. Bacon's conception of the ideal workspace, Salomon's House, was more hierarchical and bureaucratic. Whereas Hugh Plat was deeply embedded in the messy, decentralized world of Elizabethan London science, Bacon was an outsider to that world and held himself aloof from it, severely criticizing its values, practices, and personnel.

While these stories present unfamiliar people like Valentine Russwurin and put us in uncomfortable places like the King's Bench prison, they recover a moment in the history of the Scientific Revolution that has been not irretrievably

lost but only misplaced. My intention was to write a book that could serve as a kind of Baedeker's guide to a strange and unfamiliar City in an effort to help readers explore this overlooked landscape and its inhabitants by immersing them in the sights, sounds, smells, and personalities of science as it was understood in London during the Elizabethan period. At the end of the book, for readers interested in what I think these stories have to offer historians of science and the urban experience, there is a coda in which I try to situate my work in the context of other scholarship in the history of science in general and early modern science in particular. Scholars who have thumbed through this introduction in vain for references to academic arguments about the Scientific Revolution and feel it essential to understand my methodology and point of view at the outset will want to read that coda now. But I hope that many readers will be willing instead to turn the page and slip among the naturalists on Lime Street, where our tour of the City starts with James Garret, a Flemish apothecary with some very bad news for a London publishing house. Garret will be the first of many guides who will point out the buried but still discernible social foundations of the Scientific Revolution in Elizabethan London.